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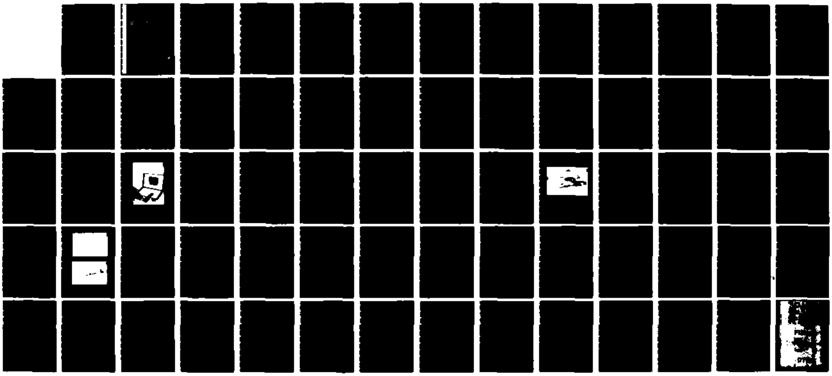

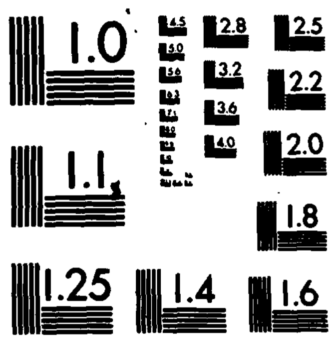

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Research and Development Technical Report
DELCS-TR-81-0338-

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EVALUATION OF ARMY REMOTELY PILOTED VEHICLE MISSION PAYLOAD OPERATOR PERFORMANCE IN SIMULATED ARTILLERY MISSIONS

Display Systems Laboratory
Radar Systems Group
Hughes Aircraft Company
El Segundo, California 90245

NOVEMBER 1983

Final Technical Report for Period April 1981 to September 1983

Prepared for
U.S. ARMY ELECTRONICS RESEARCH & DEVELOPMENT COMMAND DELCS-I,
Fort Monmouth, New Jersey, and
U.S. ARMY AVIATION RESEARCH & DEVELOPMENT COMMAND DRCPM-RPV-T
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A real-time operator-in-the-loop simulation of the Army Remotely Piloted Vehicle mission payload operations was developed and conducted. This report describes the RPV system and its mission, the operation of the mission payload system, the implementation of the simulation, and the results and their implications to design and operation of the mission payload system.

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PREFACE

Contractual support for this research was provided by the U.S. Army Electronics Research and Development Command, DELCS-I, Fort Monmouth, New Jersey, and the U.S. Army Aviation Research and Development Command, DRCPM-RPV-T, St. Louis, Missouri, contract number DAAK20-81-C-0133. Mr. A. J. Farnochi was the Army Program Manager, and Mr. M. L. Hershberger was the Hughes Aircraft Company Program Manager. The authors gratefully acknowledge the expertise and support of the following people who made the complex real time simulation of Army RPV Mission Payload Operations possible:

- Patrick FitzHenry who played the major role in directing and implementing the simulation development,
- David Craig who developed the target scenarios and with Al Farnochi collected the sensor imagery at the Fort Belvoir Night Vision and Electro-Optical Laboratory,
- Kris Bentley who developed the software to simulate the MICNS and bit error rate jamming,
- Bill Bentley, Dan Corbett, Robert Ehrenberg, John Ferrer, Richard Heineman, Kevin Martin, Ron Ray, Bill Sadowski, and Craig Spitler who developed the many hardware and software elements of the simulation,
- Richard Beale, Bill Davis, and Howie Iverson of the Lockheed Missiles and Space Company who patiently answered all the telephone calls and questions to provide the latest information on RPV system design and operation,
- Paul Thompson and Peter Whiteman of the Harris Corporation who provided information on the MICNS and bit error rate jamming,
- Frank Shields and personnel of the Fort Belvoir Night Vision and Electro-Optical Laboratory who permitted and assisted the filming of their terrain model board,
- Robert DeKinder, Jr. of OPM Smoke/Obscurants, Aberdeen Proving Ground, Maryland and George Blackman of Atmospheric Sciences Laboratory, White Sands, New Mexico, who provided tapes of cloud outlines resulting from detonations of 155mm artillery rounds.

The Hughes program manager also gratefully acknowledges the patience and support of Mr. A. J. Farnochi throughout this arduous undertaking.

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INTRODUCTION

The U.S. Army Remotely Piloted Vehicle (RPV) system consists of an air vehicle with a stabilized TV sensor and a laser rangefinder/designator, a launch unit, a recovery unit, a ground station, a remote ground terminal, associated ground support equipment, an antijam data link, and personnel to operate and maintain the equipment. The RPV system is currently under full scale engineering development with Lockheed Missiles and Space Company as the prime contractor. The mission of the Army RPV system is to conduct target acquisition, designation, and aerial reconnaissance. The RPV mission consists of five primary mission elements which support combat elements of U.S. Army divisions:

- Target acquisition — detect, recognize, identify, and locate targets
- Target designation — provide reference source for laser-guided munitions
- Artillery adjustment — provide data for engaging targets with indirect-fire weapons
- Reconnaissance — obtain information about enemy activities and resources
- Damage assessment — obtain battle-damage information.

In all of these mission elements, successful employment of the mission payload is a critical factor. Using the TV sensor with its stabilization, autotracker, and laser designator subsystems, the Modular Integrated Communications Navigation System (MICNS), and other mission payload capabilities, a Mission Payload Operator (MPO) must be able to: 1) detect, recognize, and identify targets, 2) perform artillery adjustment, 3) laser designate targets for precision guided ordnance, and 4) assess target damage to support RPV mission operations in benign and jamming environments.

The RPV system development and test has up to this time concentrated on development of the air vehicle and testing the launch, flight, and recovery operations. Test and evaluation of mission payload operations has only recently begun. While considerable basic research has been conducted to support the basic design of the mission payload system with the MICNS, operation of the system by a MPO has not been thoroughly investigated. The objective of this program was to provide a means for evaluating mission payload operations via ground-based simulation. To this end, an operator-in-the-loop real-time simulation facility was developed, and a full-task simulation of mission payload operations was conducted. The simulation evaluated both conventional artillery and Copperhead laser-guided weapons missions while in jamming and jamming-free environments. All MPO tasks and RPV system characteristics were faithfully represented in the simulation.

BACKGROUND

There are three primary RPV system operations: emplacement, mission operations, and displacement. Figure 1 shows a top level system functional flow of RPV system operations. In the simulation, we were primarily concerned with mission operations, specifically mission payload operations to accomplish target acquisition, designation, and aerial reconnaissance. These operations are largely accomplished through and controlled by a ground control station that houses the Mission Commander (MC), the Air Vehicle Operator (AVO), and the Mission Payload Operator (MPO). A cutaway view of the RPV truck-mounted ground control station is shown in Figure 2. The MPO is the principal RPV system operator who controls the mission payload system to accomplish the target acquisition, designation, and aerial reconnaissance mission operations. A brief description of the MPO's tasks follows.

Mission Payload Operations

For the Mission Payload Operator, an RPV mission will start with a mission briefing given by the Mission Commander. This will be accomplished at a mission planning facility in the RPV Ground Control Station (GCS). Map and targeting data will be the primary information given to the MPO. The map will show the RPV flight plan and the target area; the targeting data will be extracted from a military intelligence report received at the GCS. The MC will brief the MPO and then the MPO will study the mission planning data prior to manning the Mission Payload (MP) Control and Display Console. When the MPO seats himself at the MPO console, he will setup and checkout the system.

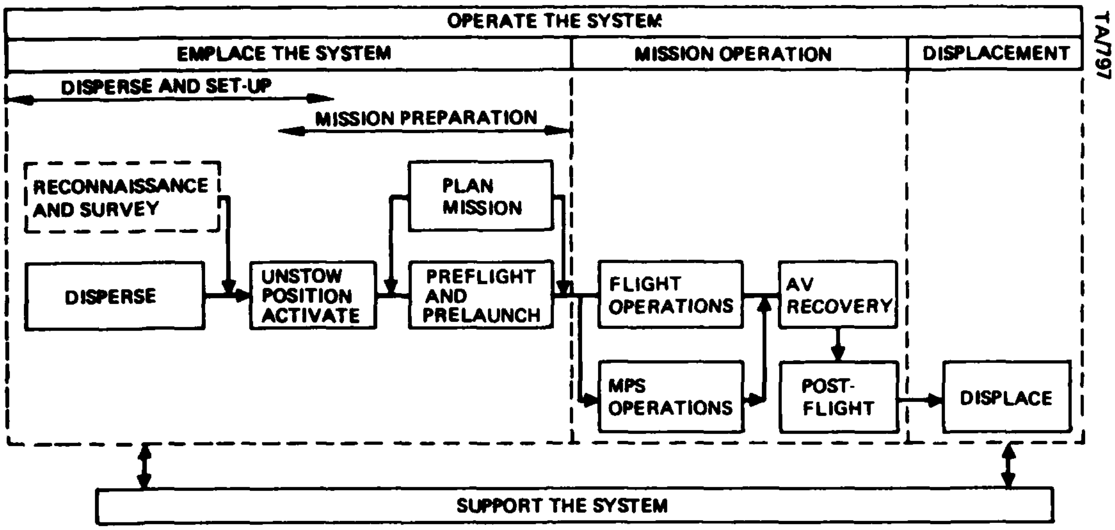


Figure 1. Top level RPV system operations.

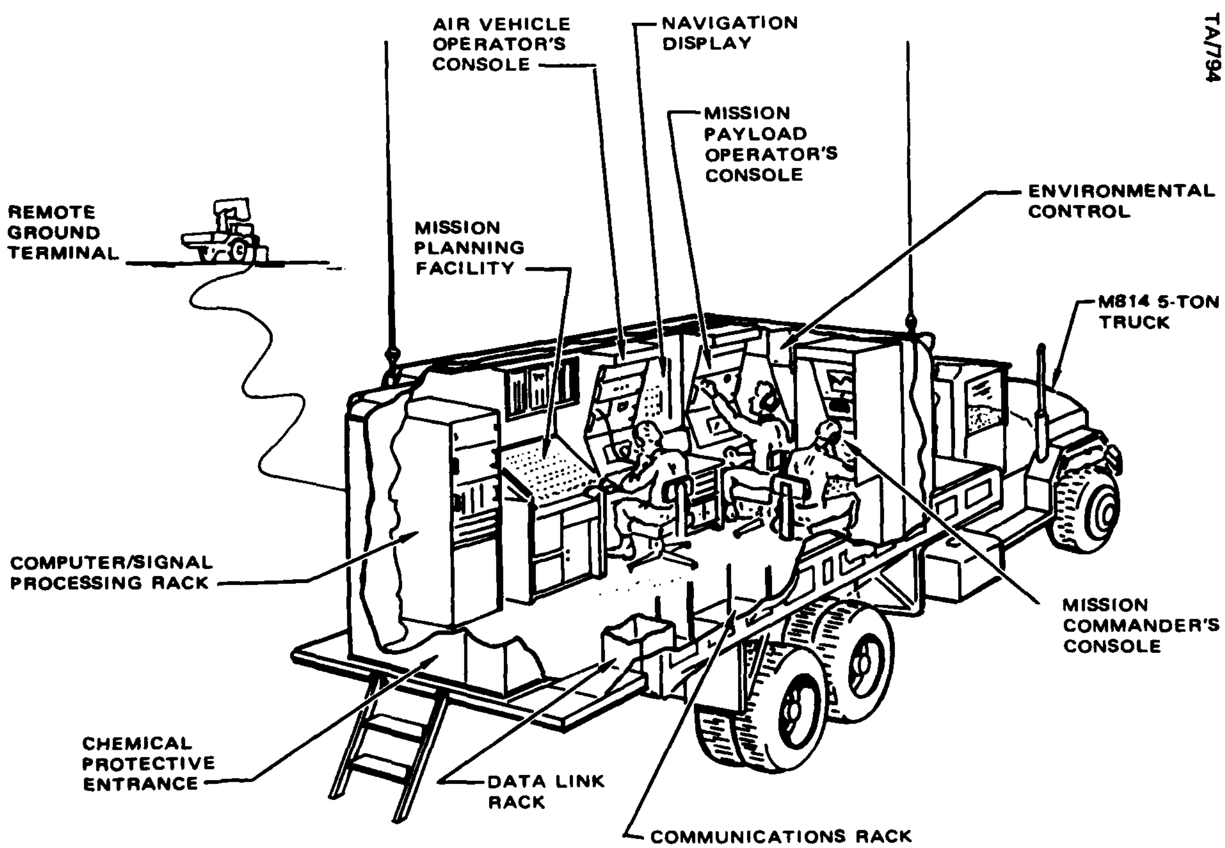


Figure 2. RPV ground control station.

The MPO will have minimal task load during the vehicle launch and enroute navigation mission phases. MPO target acquisition tasks start with target search in which the MPO will be viewing wide field of view video of the target search area. The video will be dynamically displayed in concert with the speed of the vehicle and the video frame rate. Sensor depression angle is fixed during target search. When the MPO detects what he thinks is a target, he will slew the sensor to position the suspected target under a laser aimpoint reticle in the center of his video display using a joystick control or light pen and select a narrow field of view. As soon as the narrow field of view is displayed, the operator will look to see if the object he designated in the search mode is a target of interest. If the object is not a target of interest, he will return to the wide field of view. If the object is a target of interest, the MPO will request the AVO to command air vehicle orbit. Alternatively, the orbit may be preplanned, in which case the MPO would begin his target search just prior to or just after orbit. When orbit has been established, the MPO will give a command for autotracking, preparatory to either laser designation or artillery adjustment.

In laser designation, the MPO must precision designate or track the target aimpoint. The Mission Commander will give the MPO a command when he is to lase the target for target location determination or copperhead target designation. In artillery adjustment, the MPO must switch back to a wide field of view to increase the probability that the artillery burst will be within the field of view. The MC will give the MPO warning before an artillery burst occurs. When the MPO detects the artillery burst, he will slew the sensor to position the burst under the laser aimpoint reticle using the joystick hand control or the light pen point function, and depress a laser fire pushbutton to initiate burst location computation for artillery fire adjustment. Figures 3, 4, and 5 depict the reconnaissance and target acquisition/location, artillery burst correction, and target designation mission payload operations.

The control console from which the MPO performs his tasks is depicted in Figure 6. A larger scale drawing of the main control panel is depicted in Figure 7. A detailed analysis of MPO tasks was performed during this program. Tasks and task elements were developed for the following RPV mission payload operator functions: setting up the MPO station, performing reconnaissance and target acquisition/location, performing artillery burst correction, and performing target designation. The analysis, which is contained in Table 1, was

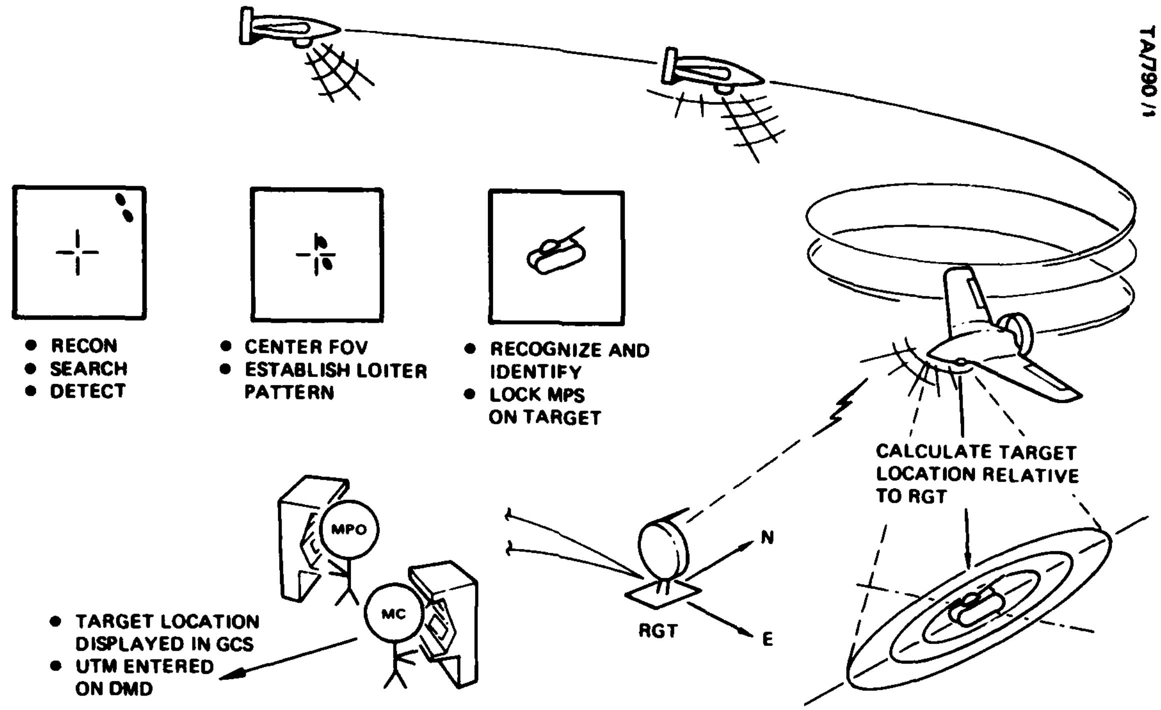


Figure 3. Reconnaissance and target acquisition/location operation.

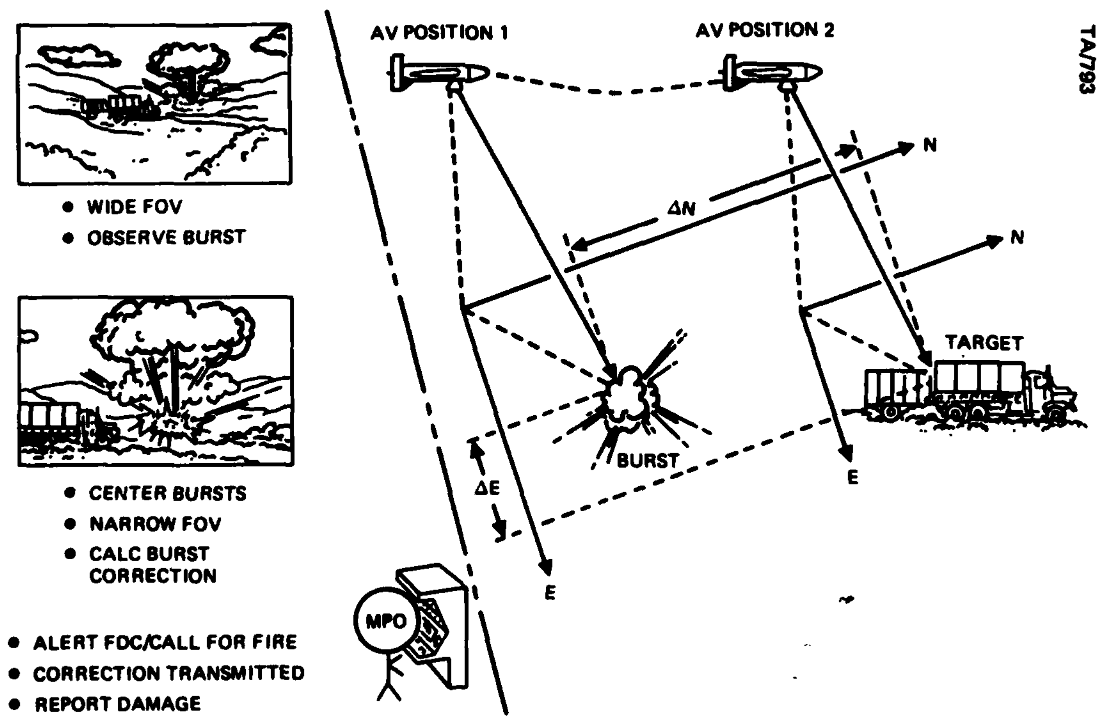


Figure 4. Artillery burst correction operation.

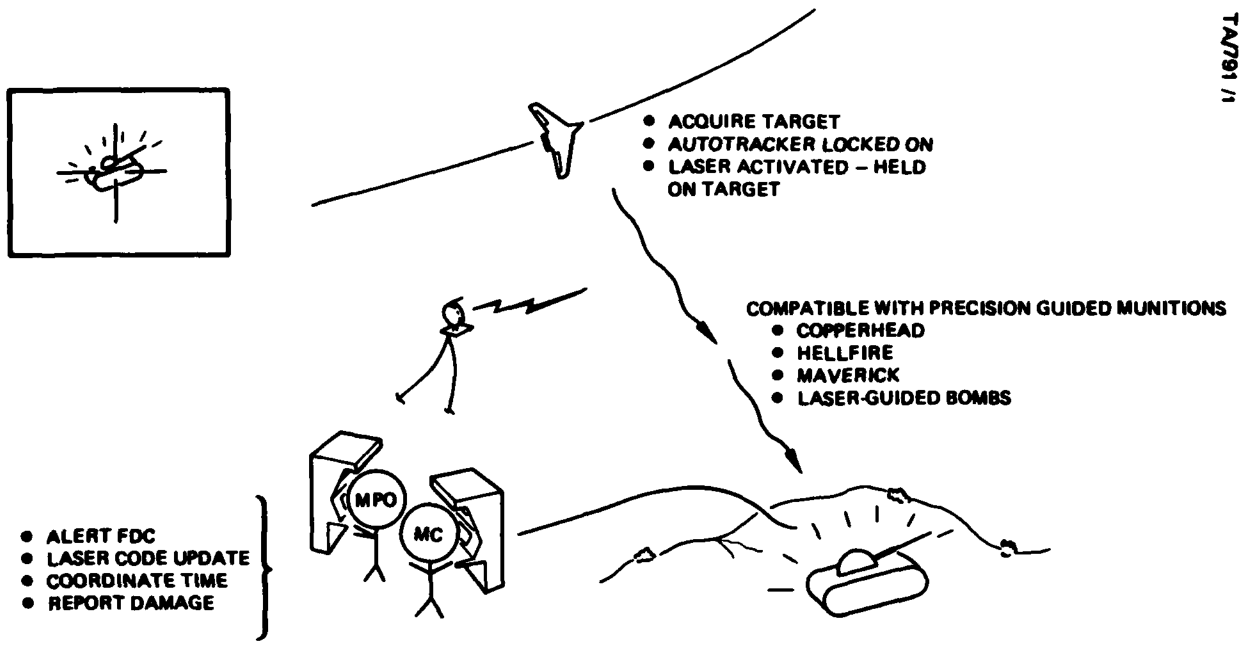


Figure 5. Target designation operation.

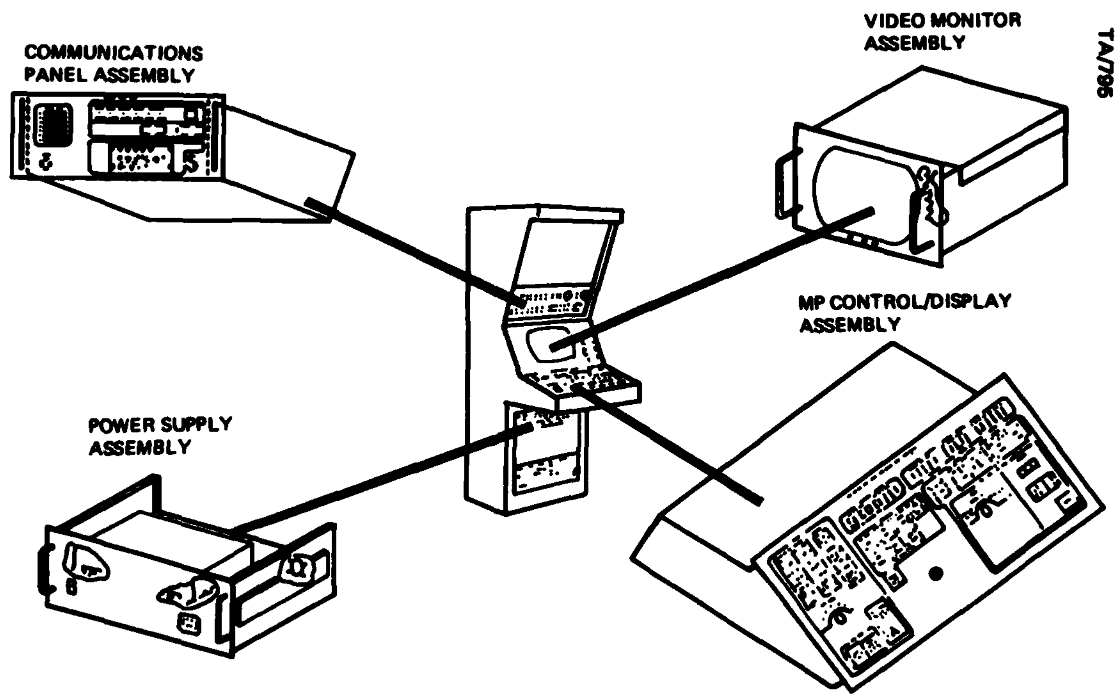


Figure 6. Mission payload operator console.

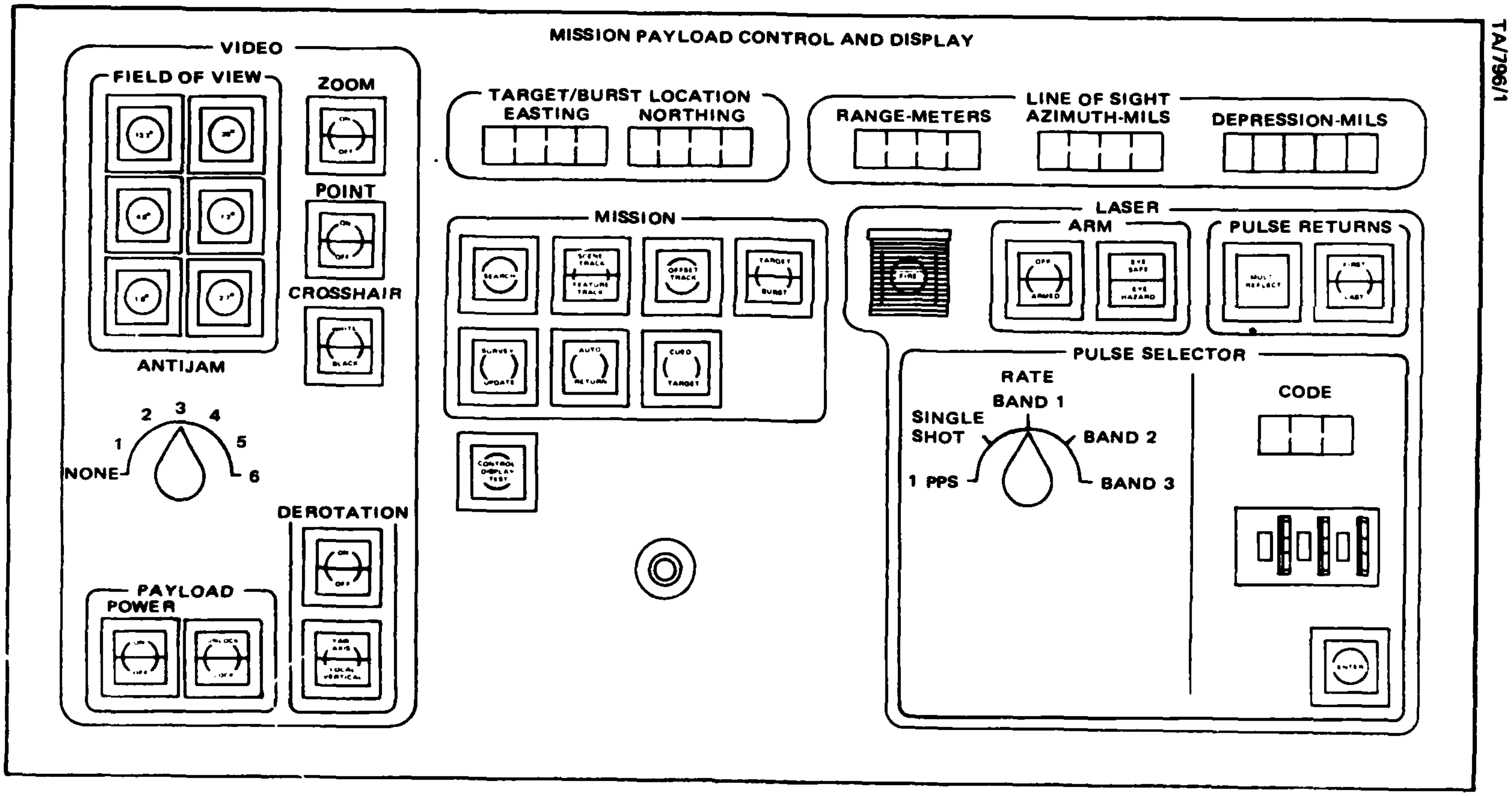


Figure 7. Mission payload operator console main control panel.

TABLE 1. RPV MISSION PAYLOAD OPERATOR TASK SEQUENCES

	Task and Task Elements	Control/Display	Remarks Reference
1.0	Review Mission Plan	Terrain Board Map Plotter	Requires Map
2.0	Set up MPO Station	MPO Console	
2.1	Set Antijam to "None"	Antijam Rotary Switch	
2.2	Select Field of View	Field of View Buttons	
2.3	Select Target Mode	Target/Burst Button	
2.4	Select Zoom "OFF"	Zoom ON/OFF Button	
2.5	Select Crosshair Polarity	Crosshair Button	Normally Select "WHITE"
2.6	Select "SEARCH" Mode	Search Mode Button	
2.7	Set Up Laser Codes		
2.7.1	Select "BAND 1"	Laser Pulse Selector Rate Rotary Switch	Set up by test conductor in Simulation. Operator briefed on band to use for Copperhead Mission.
2.7.2	Enter Three Digit Code	Laser Code Thumbwheel Switch	
2.7.3	Verify Code on LED Readout	Laser Code Readout	Readout must match code selected.
2.7.4	Enter Laser Code	Laser Enter Button	
2.7.5	Repeat Steps 2.7.1 through 2.7.4 for Bands 2 and 3		
2.8	Arm Laser	Laser OFF/Armed Button	
2.9	Select "First" Laser Pulse Return	Laser Pulse Return First/Last Button	
2.10	Checkout Controls/ Indicators	All Controls and Displays	
3.0	Reconnaissance and Target Acquisition/ Location		

TABLE 1. RPV MISSION PAYLOAD OPERATOR TASK SEQUENCES (Cont'd.)

	Task and Task Elements	Control/Display	Remarks Reference
3.1	Monitor Sensor Video	Video Monitor	
3.2	Adjust Video Brightness and Contrast	Video Monitor Brightness and Contrast Controls	
3.3	Search Target Area (Jamming Introduced)	Video Monitor	Jamming Introduced at Start of Run via Executive Computer Control in Simulation.
3.4	Note Noisey Video	Video Monitor	
3.5	Select Antijam Level	Antijam Rotary Switch	
3.6	Check Video Quality	Video Monitor	
3.7	Detect Target	Video Monitor	
3.8	Slew Sensor To Position Target Under Laser Aimpoint Reticle	Joystick Control, Video Monitor	Light Pen Designation could be used to Command Sensor Slew
3.9	Select Track Mode	Scene Track/Feature Track Button	Automatically goes into Offset Track.
3.10	Note Lock-On Indicator	Video Monitor	Track Box on Display
3.11	Select Narrow Field of View	Field of View Buttons	
3.12	Recognize and Identify Target(s)	Video Monitor	
3.13	Slew Sensor to Position Target Under Laser Aimpoint Reticle	Joystick Control, Video Monitor	Light Pen Designation could be used to Command Sensor Slew if Switch back to Search Mode.
3.14	Request AVO to Command AV Orbit	Intercom	Orbit Command was Automatic in Simulation.
3.15	Monitor Video During Transition to Orbit	Video Monitor	No Loss of Video
3.16	Inform MC of Intent to Range	Intercom	

TAB' ̄ 1. RPV MISSION PAYLOAD OPERATOR TASK SEQUENCES (Cont'd.)

	Task and Task Elements	Control/Display	Remarks Reference
3.17	Select Single Shot Laser	Laser Pulse Selector Rotary Switch	
3.18	Lift Guard on Laser Button	Guard on Laser Fire Button	
3.19	Fire Laser	Laser Fire Button	
3.20	Note Laser Fire Dot	Video Monitor	Dot Pulses at 4 PPS
3.21	Note Target Range and Coordinates	LED Range, Easting, and Northing Read-outs	MPO informs MC of target range and coordinates.
3.22	Place Guard Over Laser Fire Button	Guard on Laser Fire Button	
4.0	Artillery Burst Correction		
4.1	Monitor Autotrack on Target	Video Monitor	
4.2	Receive MC Notification of Impending Artillery Fire/Burst Correction	Intercom	
4.3	Select Burst Mode	Target/Burst Button	
4.4	Select 20° Field of View	20° Field of View Button	
4.5	Wait for Artillery Fire		
4.6	Receive Notification of Artillery Fire From MC	Intercom	MC provides verbal annoucement of impending impact
4.7	Search for Artillery Burst	Video Monitor	
4.8	Detect Burst	Video Monitor	If Burst not in FOV, MPO Slews Sensor Using Joystick or Light Pen to Search for Burst.
4.9	Deactivate Autotracking	Search Mode Button	

TABLE 1. RPV MISSION PAYLOAD OPERATOR TASK SEQUENCES (Cont'd.)

	Task and Task Elements	Control/Display	Remarks Reference
4.10	Slew Sensor to Position Burst Under Laser Aim-point Reticle	Joystick Control or Light Pen, Video Monitor	
4.11	Select Narrow Field View	Field of View Buttons	
4.12	Slew Sensor to Center Burst Under Laser Aimpoint Reticle	Joystick Control or Light Pen, Video Monitor	
4.13	Activate Autotracking	Scene Track/Feature Track Button	
4.14	Note Lock-On Indication	Video Monitor	
4.15	Inform MC of Intent on Range	Intercom	
4.16	Lift Guard on Laser Button	Guard on Laser Fire Button	
4.17	Fire Laser	Laser Fire Button	
4.18	Note Laser Fire Dot	Video Monitor	
4.19	Note Range to Burst and Burst Coordinates	LED Range, Easting, and Northing Read-outs	MPO informs MC of Range and Coordinates of Burst
4.20	Select Wide Field of View	Field of View Buttons	
4.21	Select Autoreturn	Autoreturn Button	Sensor Slews to Target Location
4.22	Activate Autotracking	Scene Track/Feature Track Button	
4.23	Monitor Video for Next Artillery Burst	Video Monitor	
4.24	Repeat Tasks 4.2 through 4.23 as Necessary Until Artillery Hits Targets		
5.0	Copperhead Target Designation		
5.1	Monitor Autotrack on Target	Video Monitor	

TABLE 1. RPV MISSION PAYLOAD OPERATOR TASK SEQUENCES (Cont'd.)

	Task and Task Elements	Control/Display	Remarks Reference
5.2	Select Target Mode	Target/Burst Button	
5.3	Select Field of View	Field of View Buttons	
5.4	Select Zoom	Zoom ON/OFF Button	
5.5	Receive MC Notification of Impending Fire	Intercom	
5.6	Select Laser Band 1	Laser Pulse Selector Rotary Switch	
5.7	Slew Sensor as Necessary to Position Target Aim-point Reticle	Joystick, Video Monitor, Offset Track Button	Requires Offset Tracking
5.8	Receive MC Command to Lase Target	Intercom	
5.9	Fire Laser	Laser Fire Button	Laser Fire Button Held in Firing Position Until Artillery Impacts
5.10	Slew Sensor as Necessary to Maintain Target Aim-point Under Laser Aim-point Recticle	Joystick, Video Monitor	
5.11	Monitor Target Video For Fire Impact	Video Monitor	
5.12	Cease Laser Firing	Laser Fire Button	
5.13	Report Target Hit or Miss to MC	Intercom	
5.14	Repeat Tasks 5.7 through 5.13 for Additional Targets		Four Copperheads Fired at 30-Seconds Intervals

based on information obtained from discussions with Army ERADCOM and Lockheed Missiles and Space Company personnel and from available Army and Lockheed RPV system documentation. Table 1 generally reflects the procedures that were used by the MPOs in the simulation.

<u>Antijam Functions</u>

A major concern in the field use of video data link systems is electronic jamming. Video data links are wide bandwidth systems, and jamming effectiveness is directly proportional to bandwidth. The Army's RPV uses a digital data link (the MICNS developed by the Harris Corporation). Bandwidth for digital systems is typically expressed as data rate in transmitted bits per second. A conventional television system with 6 bits per picture element has a data rate of approximately 50 megabits per second.

To be effective in hostile environments where jamming can be expected, countermeasures are necessary to abrogate enemy jamming. The primary countermeasure against enemy jamming of video data links is bandwidth compression/reduction. There are several techniques whereby the video data rate can be reduced using data compression transform techniques — the cosine transform encoding and differential pulse code modulation (cosine/DPCM) technique is used with the Army RPV system — or simple bandwidth reduction, such as frame rate reduction and resolution reduction. Bandwidth compression can be combined with simple bandwidth reduction techniques to achieve a considerably reduced data rate, because the factors are multiplicative. For example, a 3:1 reduction via bandwidth compression, an 8:1 reduction via frame rate reduction, and a 4:1 reduction via resolution reduction would result in a 96:1 system bandwidth compression/reduction. For such a case, our conventional 50 megabits per second television system data rate would shrink to a 0.52 megabit per second data rate. Unfortunately, few things are truly free, and bandwidth reduction/compression can degrade the quality of the sensor video information and interfere with the operator's ability to command sensor pointing.

The Army RPV system design provides seven MPO selectable levels of video data rates (antijam levels) for operation in benign and jamming environments. The seven levels are based on various combinations of video frame rate, sensor resolution, and video truncation. A fixed 2-bit per pixel cosine/DPCM bandwidth compression is used at all seven data rates. The combinations of frame rate, resolution, and truncation for any particular data rate selected depend on the RPV mission/mode. There are three such mission/modes: search, artillery, and track. Table 2 gives the values of frame rate, resolution, and truncation currently provided in the RPV system design for the 21 combinations of the seven data rates (antijam levels) and the three mission/modes.

TABLE 2. RPV ANTIJAM LEVELS

ANTIJAM LEVEL	*DATA RATE, Mb/s	FRAME RATE, FRAMES/ SECOND	RESOLUTION	TRUNCATION	MISSION
None	4.6	15/2	640 x 480	None	Search
	4.6	15/2	640 x 480	None	Artillery
	4.6	15	320 x 480	None	Track
1	2.3	15/4	640 x 480	None	Search
	2.3	15/4	640 x 480	None	Artillery
	2.3	15	640 x 480	320 x 240	Track
2	1.15	15/8	640 x 480	None	Search
	1.15	15/4	320 x 480	None	Artillery
	1.15	15/2	640 x 480	320 x 240	Track
3	0.576	15/16	640 x 480	None	Search
	0.576	15/4	320 x 240	None	Artillery
	0.576	15	640 x 480	160 x 120	Track
4	0.288	15/32	640 x 480	None	Search
	0.288	15/8	320 x 240	None	Artillery
	0.288	15/2	640 x 480	160 x 120	Track
5	0.144	15/64	640 x 480	None	Search
	0.144	15/16	320 x 240	None	Artillery
	0.144	15/2	320 x 480	80 x 120	Track
6	0.072	15/128	640 x 480	None	Search
	0.072	15/16	160 x 240	None	Artillery
	0.072	15/4	320 x 480	80 x 120	Track

*At 2 bits per pixel

Mission Payload Control Console Functions

In the simulation, the functions available to the MPO on the main control panel of the MPO's control station were implemented to reflect the current Army/Lockheed design. In some cases, design changes have only recently been recommended to the Army and are not yet official. In effect, MPO console operations are still in a state of flux. To the extent possible, and when concurrence was obtained from the Army, these recent (up to August 1983) design changes were implemented in the simulation. The functions central to mission payload operations and implemented in the simulation are described here.

Video Functions

The video functions implemented in the simulation included: Field of View, Antijam, Zoom, Point, and Crosshair polarity. Six diagonally measured fields of view are available to the MPO: 20, 13.3, 7.2, 4.8, 2.7, and 1.8 degrees. The 13.3, 4.8, and 1.8 degree fields of view are electronically obtained from the 20, 7.2, and 2.7 degree optical fields of view, respectively. The electronic fields of view provide an increased scale factor, but resolution (resolution lines across an object) does not change from the corresponding optical field of view.

The antijam control determined the particular video data rate and thereby the particular combination of frame rate, resolution, and truncation as given in Table 2.

Zoom provided the option of electronically expanding the sensor video to fill the video display when video truncation occurred at appropriate antijam levels in the Target mode.

The Point function was used in combination with the light pen to effect sensor slewing. The accuracy of light pen sensor slewing is a function of an algorithm which assumes a 2.5 kilometer range to target. As the actual range to target departs from 2.5 kilometers, the accuracy of slewing degrades. In actual practice, it will take one to three light pen designations to achieve a 50-meter accuracy. Originally, the Point function was designed for use with low frame rates (1 frame per second or less) and was not operable with higher frame rates. A recent design change included in the simulation permits the Point function to be used at any frame rate.

Crosshair polarity allows selection of white or black laser aimpoint reticle, track box, and light pen cueing box symbology on the video display.

Mission Mode Functions

The Search mode always provided full resolution sensor video without truncation. It is used primarily for initial target detection and recognition when sensor video image quality is critical. Scene Track and Feature Track are autotracking modes. The Westinghouse autotracker is a correlation tracker. In Scene Track, correlation is done over a large area of the video image. In Feature Track, four areas of image correlation are provided. The autotracker automatically selects the smallest area it can maintain track on. If the auto tracker cannot maintain track at the largest area, it will automatically switch to scene track.

Offset Track is used to slew the sensor when the autotracker is engaged. When the MPO selects Scene Track or Feature Track, Offset is automatically engaged. The MPO can then use the Joystick to slew the sensor. When the MPO slews the sensor in offset, both the sensor image and the track box symbol are slewed on the video monitor. The amount of slewing (how far the video image and track box can be moved) depends on whether Scene Track or Feature Track is engaged, and in Feature Track, the amount of slewing depends on the correlation area. If Scene Track and Offset are enabled, the sensor and track box have been slewed, and Offset is then disabled, the new sensor location and the track box will be repositioned at the center of the laser aimpoint reticle at the center of the video display. This feature allows the MPO to "walk" the sensor image across the display. However, it may take several iterations of enabling and disabling the Offset function and sensor slewing to move the image any appreciable distance across the display. If Feature Track and Offset are enabled, the sensor and track box have been slewed, and then Offset is disabled, the sensor video and the track box will "jump" back to the position they were at before the sensor was slewed.

The Target/Burst function is used to select target or artillery operations. The target mode is used for Copperhead laser designation operation; the burst mode is used for artillery burst correction operation. The selection of Target or Burst in combination with the antijam level selected determined the combination of frame rate, resolution, and truncation provided to the MPO. Video truncation, for example, only occurred when Target mode is selected in Antijam levels 1 through 6.

Survey update is a navigation function. It was not used in the simulation.

Activation of the autoreturn function causes the sensor to slew to the last point autotracked. Its primary use is to slew the sensor back to the target tracked after an artillery burst has been designated (slewed to the laser aimpoint reticle) so the MPO is set up for the next artillery round which should fall near the target.

The Cued Target function is intended to be used to slew the sensor to preplanned coordinates. The coordinates are set into the system by the MC. When the RPV is within 2500 meters of the set-in coordinates, the Cued Target button will illuminate. If the MPO then depresses the Cued Target button, the sensor will slew to the set-in coordinates. According to Lockheed personnel, the Cued Target function may be changed to work in conjunction with light pen sensor slewing. The details of this change are sketchy, and this change was not implemented in the simulation.

Sensor Slewing Functions

The MPO can achieve sensor slewing via the Joystick, the Light Pen, or by activating Autoreturn or Cued Target; the latter two methods were described in preceding paragraphs. The Joystick outputs a rate command to the video sensor. An 8-pixel deadband is provided to prevent drift. A shaping function, which varies with the sensor field of view in the Search mode, and in the Offset track mode, is also part of the Joystick slewing function.

Light Pen sensor slewing is operable in the Search mode at any frame rate as previously described. Light Pen sensor slewing is accomplished by placing the Light Pen on the video display, pushing the pen against the display to activate a switch built into the pen, and depressing the Point button. When this is done a cueing box will appear on the display for 5 seconds and the sensor will slew to position the point designated by the Light Pen closer to the laser aimpoint reticle. The Point button must be depressed before the cueing box goes away. In the RPV system, the cueing box is displayed on the MC's and AVO's video displays. The MC and AVO have light pens to cue the other operators to any area of potential interest, but no Point function to slew the sensor. Use of the light pen point function also causes the sensor platform to go into a self-stabilization mode.

Laser Functions

Lasing is used to obtain range to an object, refine target or burst location data through accurate range information, and laser designate targets for laser-guided ordnance. Laser fire and arming functions were used in the simulation. In order for the laser to be fired, it had to be armed. In the simulation, this was preset and never changed. When armed, the Eye Hazard indicator is illuminated. The laser pulse return was always set at First, the laser pulse selector was set at Band 1, and the laser code was set to

563 in the simulation. The laser Fire button has a spring-loaded plastic guard which must be raised to fire the laser. Continuous firing of the laser requires the MPO to hold the Fire botton in a depressed position.

LED Readouts

Light emitting diodes provide Target/Burst Location, and sensor Range-Meters, Azimuth-Mils, and Depression-Mils line-of-sight information. Easting and Northing Target/Burst Location in UTM coordinates and Range are generated when autotracking and following a laser designation. Sensor azimuth and depression angle information are continuously available.

Vehicle Flight Geometry

The Aquila RPV is a tailless mid-wing monoplane with a rear-mounted pusher propeller engine. It has an operating speed range of 60 to 170 kilometers per hour, a maximum service altitude of 2,774 meters, and a maximum cruise endurance of 178 minutes. The mission payload platform allows 360-degree azimuth pointing and +15 to -90 degrees elevation pointing. The flight path is controlled from the Air Vehicle Operator's (AVO) console in the ground control station. The Aquila can be flown automatically using as many as 16 waypoints or under real-time manual control by setting altitude, airspeed, and heading digi-switches and a turn rate rotary switch on the AVO's console.

In the simulation, the airspeed, altitude, and sensor depression angle were always 130 kilometers per hour, 1000 meters, and depressed a down-look angle of 30 degrees, respectively. Implementation of the RPV mission payload functions and flight geometry as described in the preceding pages is discussed in the following section.

SECTION 2
SIMULATION IMPLEMENTATION

OVERVIEW

Evaluation of the mission procedural algorithms for use under jamming conditions requires a simulation of the major tasks and mission environment of the Mission Payload Operator (MPO). The major tasks of the MPO include target search, detection, acquisition, and track, laser designation, and artillery adjustment. These mission activities and their associated subtasks were simulated using existing computers and equipment in the Hughes Simulation and Computing Center (SCC). A block diagram of the principle components of the simulation are shown in Figure 8 and will be described in the following paragraphs.

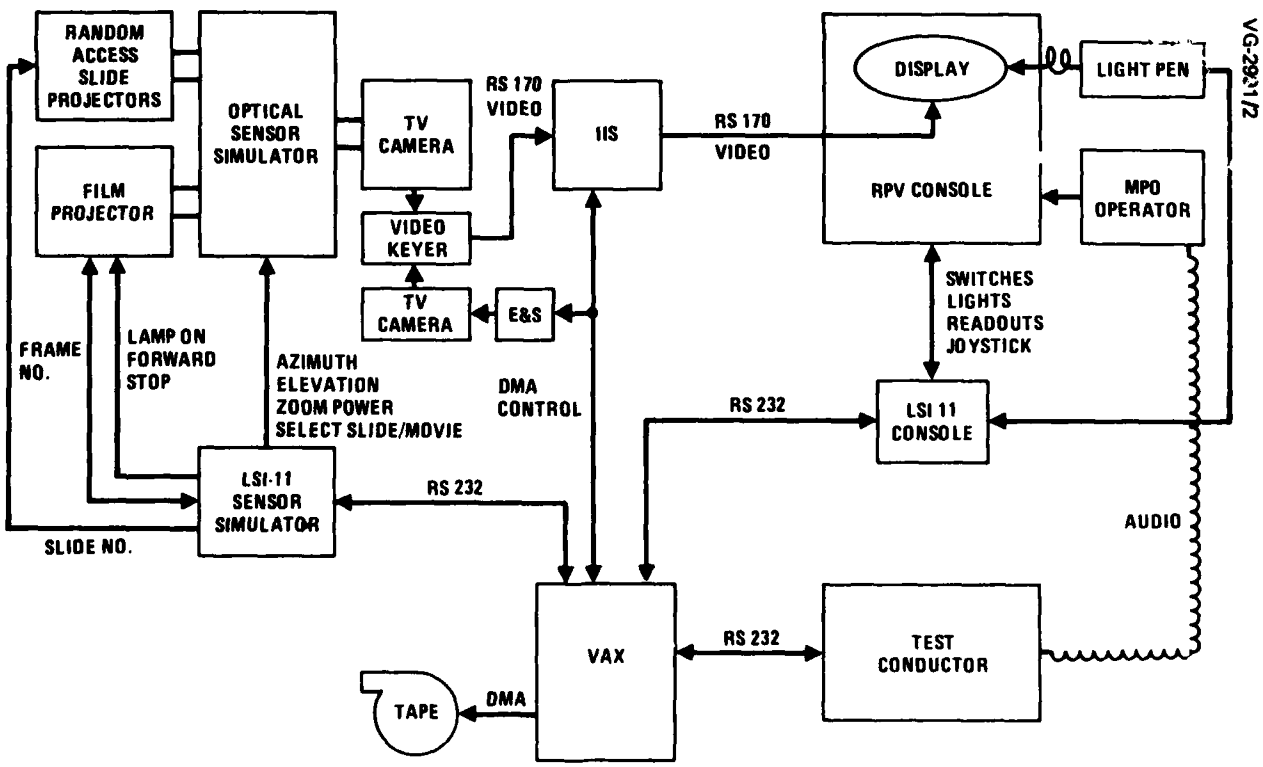


Figure 8. RPV simulation block diagram.

The block diagram of Figure 8 shows sources of sensor video to accommodate fields of view from 20 to 1.8 degrees diagonal while maintaining at least 525-line TV resolution and necessary scene dynamics. The search video source used a random access 35-mm slide projector to provide a dynamic image of the terrain as it would appear to the on-board sensor. A second random access 35-mm slide projector provided detailed terrain images for target acquisition, artillery adjustment, and laser designation, using wide and narrow fields of view. A more complete description of the use of the video sources will be provided, following an overview of the remainder of the simulation implementation.

The two projectors were coupled to a television camera which converted the optical image to standard RS-170 video. The LSI-11 microprocessor which controlled the sensor simulator also provided projector remote control, slide selection, and selection of the video source. This LSI-11 and the other LSI-11s used in the simulation were equipped with the necessary conversion hardware to provide both analog and digital input and output. The LSI-11s were located near the equipment they control which minimized the length of the cables between the equipment and the processors. A single line connected the peripheral LSI-11 to the central VAX 11/780. By distributing the processing, the data rate to the VAX 11/780 was significantly reduced, and the length of noise-susceptible analog signal cables was minimized.

The Stanford Technology Corporation International Imaging System (I^2S) image computer performed virtually all of the bandwidth reduction/compression simulation functions under control of a VAX 11/780 computer. Resolution, frame rate, image truncation, electronic zoom, image freeze, gray scale manipulation, and jamming were among the functions which the I^2S performed in the simulation. The particular combinations and levels of each of these functions were dynamically altered in real-time by the VAX 11/780. The I^2S also has graphic overlay capability and a built-in vector generator which allowed dynamic symbology to be superimposed over the sensor video.

The video output of the I^2S was displayed on a high quality TV monitor for viewing by the MPO in the simulation. The display was physically located in a replica of the MPO control console with all of the controls, indicators and switches to be found in the actual system. The exact layout of the panel and the complement of controls, shown in Figure 9, includes a joystick, light pen, field of view select switches, autotracker controls, laser controls, sensor package controls, and various indicators. The controls were read and

Figure 9. Mission payload operator console.

the indicators driven by a LSI-11 interfaced to the VAX 11/780 computer. The link between the processors was RS-232.

Control of the simulation was accomplished by a test conductor via a CRT terminal into the VAX 11/780. All variables and initial conditions were set from this terminal either manually or by reference to a disc file which contained previously selected combinations and levels of variables. This terminal was located adjacent to the MPO console in the simulation. The following paragraphs detail the implementation of the various components of the simulation outlined above.

DETAILED FUNCTIONAL DESIGN

Target Video Sources

The target video source was two random access 35-mm slide projectors. A TV camera viewed the slides through a zoom lens and image motion translation mirrors to generate a RS 170 signal. The slides were obtained by photographing the NVEOL terrain board to obtain a 46-degree cruise, a 46-degree orbit, and an 18-degree orbit slide for each target. A total of 76 such target slide sets were obtained. Figure 10 depicts the sensor image simulation equipment.

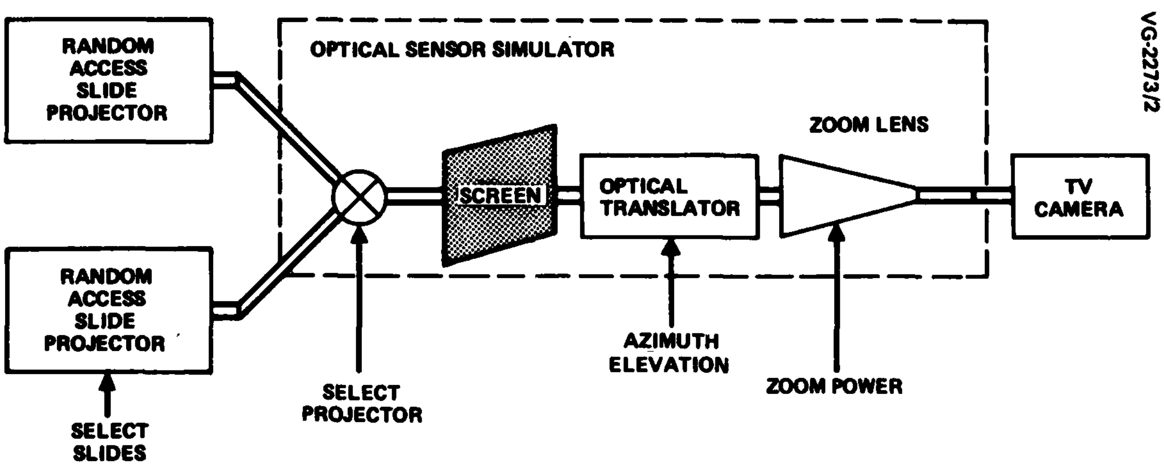


Figure 10. Sensor simulation equipment block diagram.

Depending on the RPV flight mode (cruise or orbit flight) and the selected field of view, the appropriate slide of the target was selected using the random access capability of the projectors. To minimize the time required to select a slide, prediction algorithms in the LSI-11 continually kept the correct slide ready for view. Using the positionable raster, the ground location designated during search was centered on the display. If the MPO wished to slew the sensor to search for the target, this was achieved with the digitally controlled translation mirrors in the sensor simulator.

If the MPO confirmed that the detected object was a target, simulation proceeded to precision tracking or artillery adjustment. If the object was not a target, the operator continued in the search mode.

Although the scene viewed during the search process was a static photograph, little loss of fidelity resulted. Using the azimuth and elevation translation capability of the sensor simulator and the zoom lens, a realistic view of moving terrain was presented to the MPOs.

Artillery Adjustment/Laser Designation Video Source

The apparatus for this video source was the same used for the target search video. The RPV went into an orbit automatically at about 2.5 kilometers from the target to allow either precision tracking for laser designation or artillery adjustment. The 46-degree orbit slide in the 35-mm projector provided the target scene during search in orbit.

If the simulation called for a narrow field of view, the 18-degree slide provided a displayed sensor field of view as small as 1.8 degrees. If the target was not centered in the field of view during the 46-degree cruise or orbit phase, the error was included when the switch to the 18-degree slide was made.

Optical Switch

An optical switch selected one of the random access slide projectors for transmission to the I^2S. Selection was under control of the LSI-11 which in turn was controlled by the VAX 11/780.

Autotracker

The Westinghouse autotracker, which is part of the Mission Payload System, was functionally simulated in the VAX 11/780 using a describing function that represented autotracker error for realistic RPV and environmental operating conditions.

Microprocessor Control

The LSI-11s were programmed in "C" language to maximize real-time execution efficiency. Standard routines and interfaces were used to maximize commonality among processor and software. Wherever possible, standard off-the-shelf interfaces were used. Software development was accomplished using the VAX 11/780 computer which can emulate LSI-11 code.

Video Image Processing

The Stanford Technology Corporation I^2S image computer was the heart of the data link and bandwidth reduction/compression part of the simulation. Resolution reduction, frame rate, truncation, electronic zoom, freeze, bit error rate jamming, and gray scale manipulations were accomplished digitally using this equipment. Additionally, laser aimpoint reticle, track box, and cueing box symbology was generated using the graphics capability available.

Incoming video is converted to digital format with 8 bit accuracy using a 10 MHz A/D converter. The data pass through a pipeline processor and a feedback Arithmetic Logic Unit (ALU) on the way to one of several possible 512 by 512 memories as indicated in Figure 11. From any of these refresh memories, the data may be displayed by going through a second pipeline processor to a D/A converter and on to a CRT display. The interconnections between pipeline processors, memories, ALU, A/D, and D/A are all under software control allowing highly versatile architectures.

Transmission delay and frame rate reduction were accomplished by displaying from one memory while filling a second memory with new data. At the desired frame rate, the memories were "flip-flopped" as illustrated in Figure 12. In Figure 12a, memory A is being filled while memory B is being displayed. Figure 12b shows the configuration after the next frame update. The function of memories A and B change at each update. For example, at 7.5 frames/second, memory function would change every four TV video frames. One frame time is required to get the video to memory A in Figure 12a and the next three frame times no new data would be digitized. At the fifth frame time the memory function would be changed to that shown in Figure 12b and a new frame of data digitized into memory B while the display would show the contents of memory A.

Resolution reduction was accomplished using the processing capability of the pipeline processors and the ALU. Simulation of the case where bandwidth is reduced by transmitting every other pixel, thereby halving horizontal

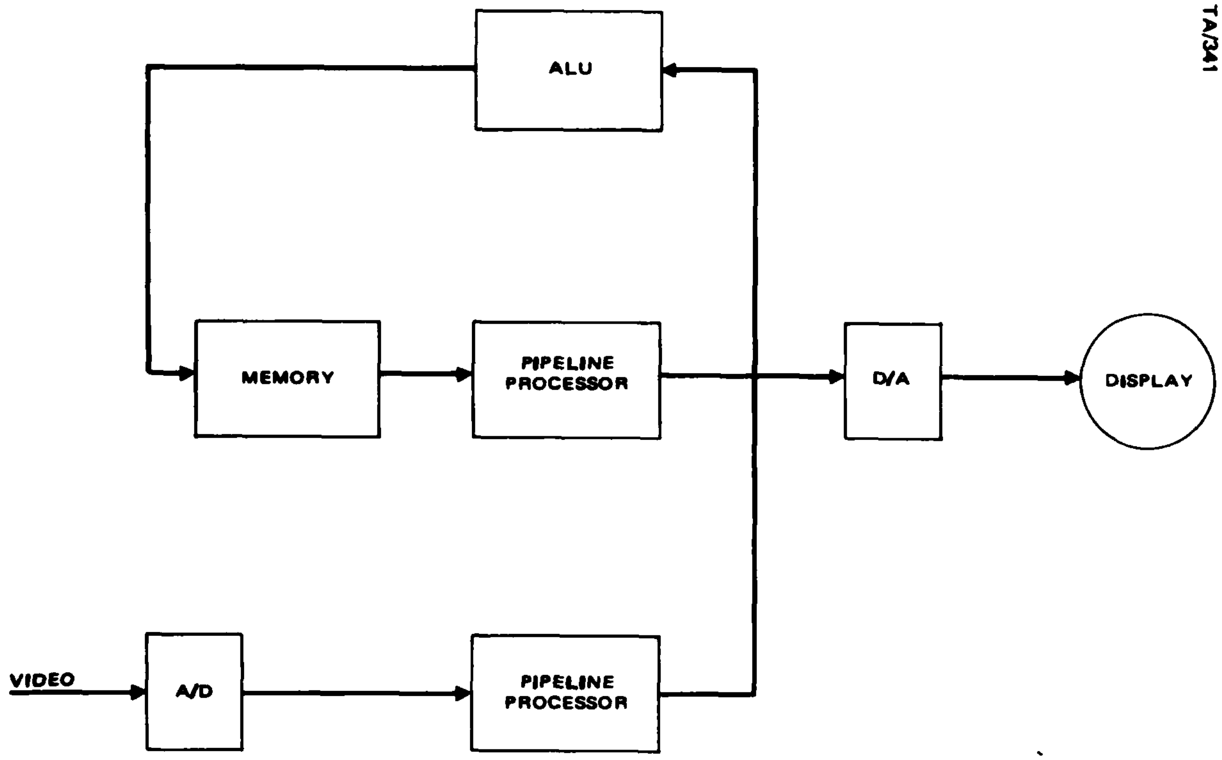


Figure 11. I^2S functional block diagram.

resolution, was accomplished as follows. A 512 by 512 "region of interest" mask was defined in one of the graphic memories with a "1" in all of the odd columns and a "0" in all of the even columns. This "region of interest" would then be used by the ALU to pass the video unchanged if the mask value is "1" and to output a 0 if the mask value is "0". Thus, as the digitized video is being sent to the refresh memory, it is modified to keep odd column pixels and delete even column pixels.

This image with every other pixel removed was loaded into two memories at the same time. These two memories were connected to a single pipeline processor where one would be shifted a single pixel to the right and then added to the second memory. The result was an image with each pixel replicated once horizontally. This image was fed back to a refresh memory for display at the next frame update time. The same process was extended to two dimensions of resolution reduction with only modification.

Truncation was also simulated by using a mask to define the area of the image to be kept. However, truncation may be followed by electronic zoom, and the built-in zoom capability of the pipeline processor allowed this to be accomplished with a single software command. Electronic zoom values of 2 and 4 could be commanded about any point in the image. The hardware eliminated

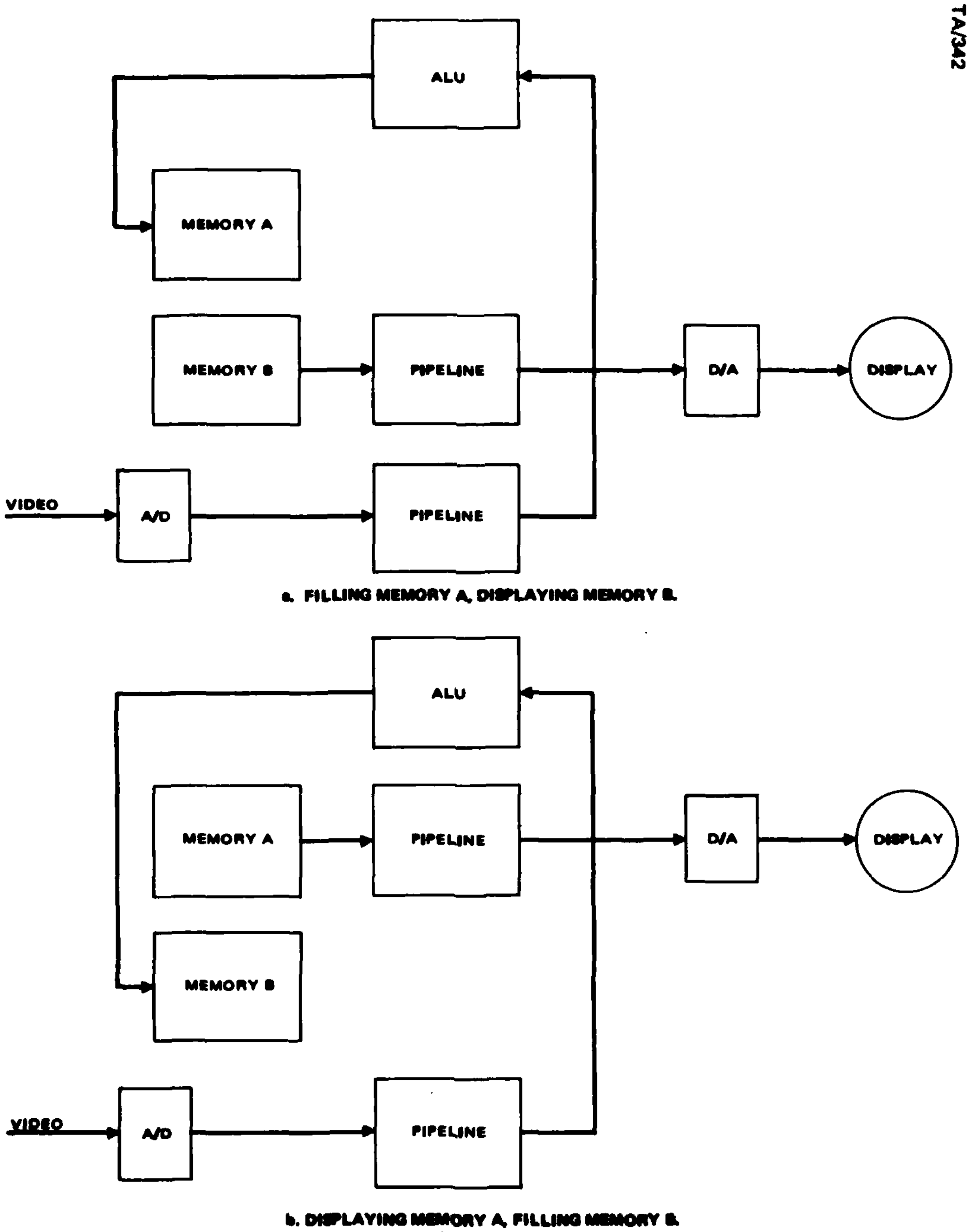


Figure 12. I^{2}S memory "flip-flop" function.

(truncated) that portion of the video which would be outside the display after the zoom and automatically replicated the remaining pixels to maintain a constant displayed image size.

Gray scale modification was accomplished using the built-in hardware look-up tables which used the incoming value as an address in a table to look up the output value. The contents of the hardware tables could be loaded with any brightness transfer function by the VAX 11/780 or the embedded LSI-11.

Artillery Burst Generation

For artillery missions, it was necessary to simulate the burst of artillery shells (conventional artillery and Copperhead) at various locations within the sensor field of view. The MPO was required to detect and designate these bursts to allow the system to compute the needed adjustment. It can be expected that following the transmittal of each adjustment to the artillery battery subsequent bursts will be closer to the target. This means that the simulation had to be able to place a burst at any location on the display. Further, the burst will have to be a dynamic sequence that matches the appearance of an actual artillery burst with smoke and dust clouds.

To accomplish this in the simulation, the Evans and Sutherland Multipicture System generated artillery bursts based on digitized outlines of actual smoke burst obtained from the U.S. Army Atmospheric Science Laboratory, White Sands Missile Range. The size and location of the burst were determined by the ignition location, RPV location, sensor pointing angle, and sensor field of view. The Evans and Sutherland generated burst image was converted to RS 170 by a scan converter and mixed into the target scene image from the sensor simulator.

The placement of artillery bursts with respect to detected targets was derived from work conducted at CSTAL, ERADCOM. Based on artillery accuracy data contained in FM 101-60-3, Joint Munitions Effectiveness Manual, "Effectiveness Data for Howitzer, 155 mm", a computer model of the artillery adjustment process using the RPV as a forward observer was developed. The model employed Monte Carlo techniques to investigate the effects of the range from the artillery battery to the target, the angular location of the RPV with respect to the target and the battery, and the size of the observable footprint. This effort is reported in the document, "Analysis of the Employment of a RPV for Artillery Correction", by W. James Mills CSTAL, November 1980.

The computer model was run in September 1982 to provide the data required for the RPV MPO simulation. A range of 12 Km from artillery battery to target and 45 degree artillery battery/target location/RPV azimuth angle were selected as the conditions for use in the simulation. Figure 13 shows an artillery burst generated in the simulation approximately 5 seconds after impact.

Figure 13. Simulated artillery burst 5 seconds after impact.

Executive Computer Control

The VAX 11/780 computer controlled and coordinated all of the other components of the simulation. A real-time executive routine provided timing and calls for the other software routines as required based on real-time events and the particular parameters of the simulation in progress. Models of the RPV vehicle, navigation system, and sensor dynamics were computed to simulate a 10 Hz command uplink as well as automatic uplink shutdown and link start up delays. All data collection was accomplished by the VAX 11/780 by extracting the required variables from the common block and transmitting them to disc for storage and later processing.

SECTION 3
SIMULATION STUDY DESIGN AND EXECUTION

SIMULATION METHODOLOGY

Objectives

The RPV simulation program was designed to exercise all major MPO procedures, to evaluate their effectiveness, and to identify any problem areas. The primary simulation variable was jamming level of the video link, which was examined for both the conventional artillery and Copperhead ordnance missions. Additional objectives of this simulation included evaluation of major MPO console controls, mission task sequences, and mission timelines. Questionnaire data were collected to augment the empirical performance data.

Approach

The overriding consideration of this simulation program was to gather performance data which corresponded to operational mission requirements. This orientation resulted in the development of simulation scenarios which matched the "real world" in every possible way, while providing for controlled and systematic data collection.

The RPV simulation was constructed around complete operational scenarios; the simulation was effectively "whole-task". Copperhead and conventional artillery missions were presented in a random order, as were different levels of jamming. No feedback was provided during a mission which would not have been available in an operational setting and, within certain limits, the Mission Payload Operator (MPO) was allowed to continue with a mission even after errors were committed; errors will be committed in combat, and it is important to identify them, as well as their consequences, at an early point in system development.

Four members of the Hughes technical staff were used as MPOs for this study. Two of these participants had previous experience with military target identification tasks, but none were associated with the RPV program or MPO duties.

Preparation

The MPO console was employed as a stand-alone device for this simulation. Mission Commander (MC) and Air Vehicle Operator (AVO) duties were performed by the test conductor seated at a computer terminal in the same room. Operation of the MPO console controls matched those of the actual Aquila Mission Payload System Operations as of August 1983.

Four representative target types were used for the conventional artillery missions, and four different types were used for the Copperhead missions. Artillery targets were SA-6 SAM missiles in launch configurations, supply vehicles in a convoy, supply vehicles in a staging area, and ZSU-23/4 AAA artillery in a staging configuration. Copperhead targets were motorized rifle company on a road, motorized rifle company in an assault configuration, tank company in a static defense configuration, and tank company crossing a river. The Copperhead targets were distinguished by the presence of tanks in the target complex, making the use of this special ordnance most appropriate. Diagrams of typical configurations for these targets were presented in Figures 14 through 21.

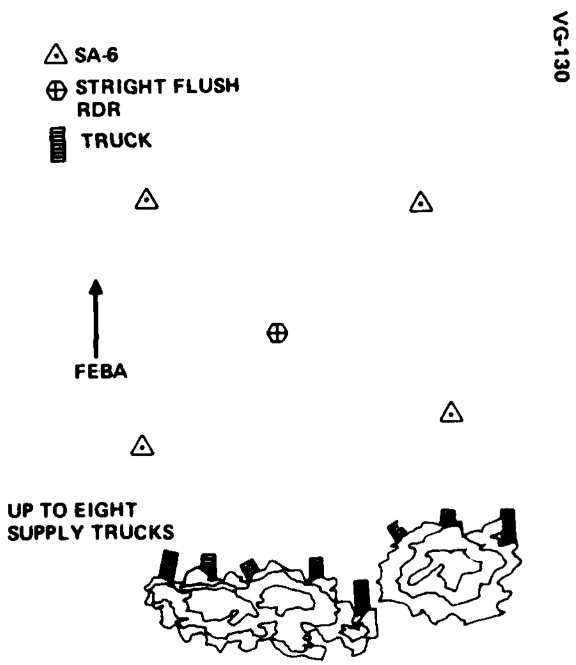


Figure 14. SA-6 group in launch configuration.

Video bit error rate jamming was introduced into the mission to evaluate MPO performance under the varying data rates associated with different antijam levels on the MPO console. Three levels of jamming and a no jamming condition were employed in the study. The three jamming levels are herein referred to as levels 1, 2, and 3, from lowest to highest jamming, respectively. This nomenclature is used to obviate classification of this report. The "no jamming"

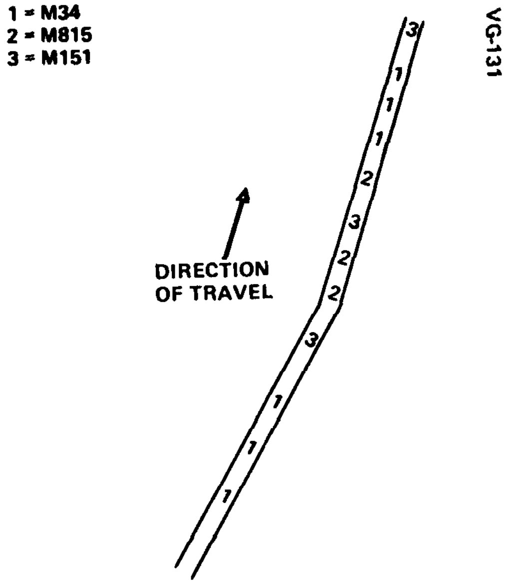


Figure 15. Supply vehicles in convoy.

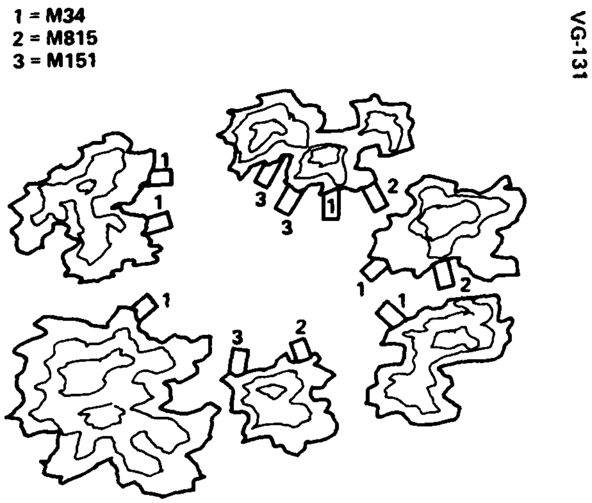


Figure 16. Supply vehicles in staging area.

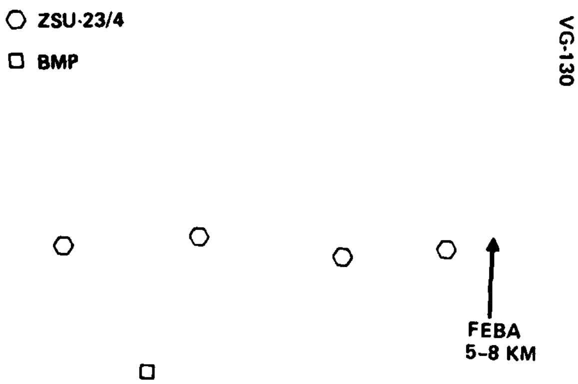


Figure 17. ZSU-23/4 artillery in staging configuration.

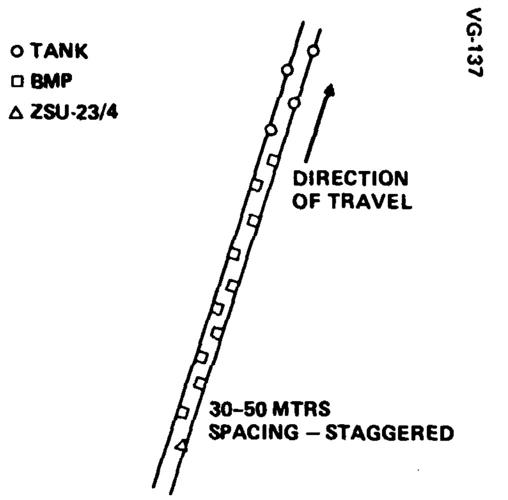


Figure 18. MR company on road.

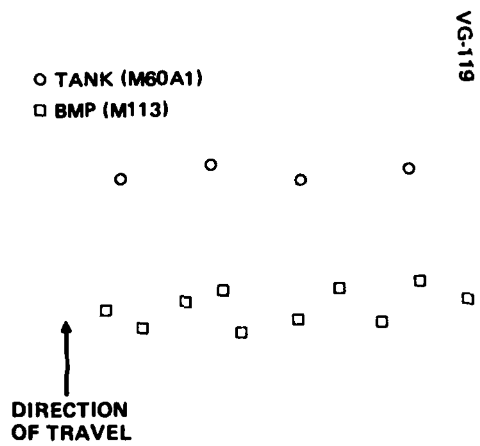


Figure 19. MR company in assault.

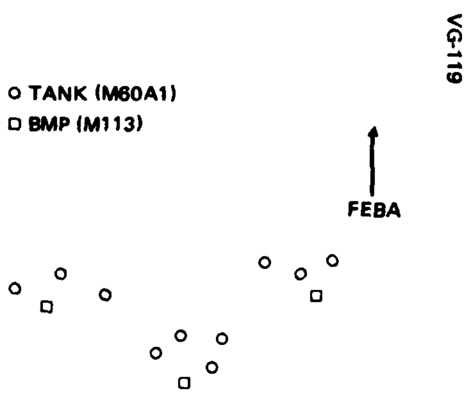


Figure 20. Tank company in static defense.

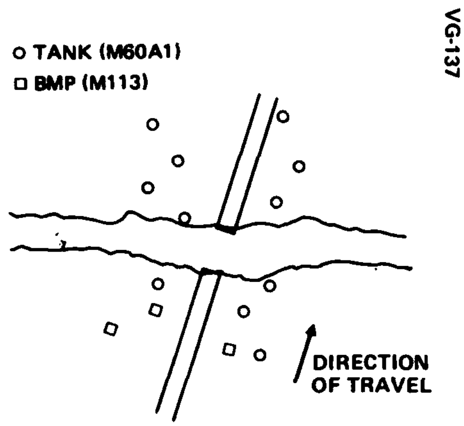
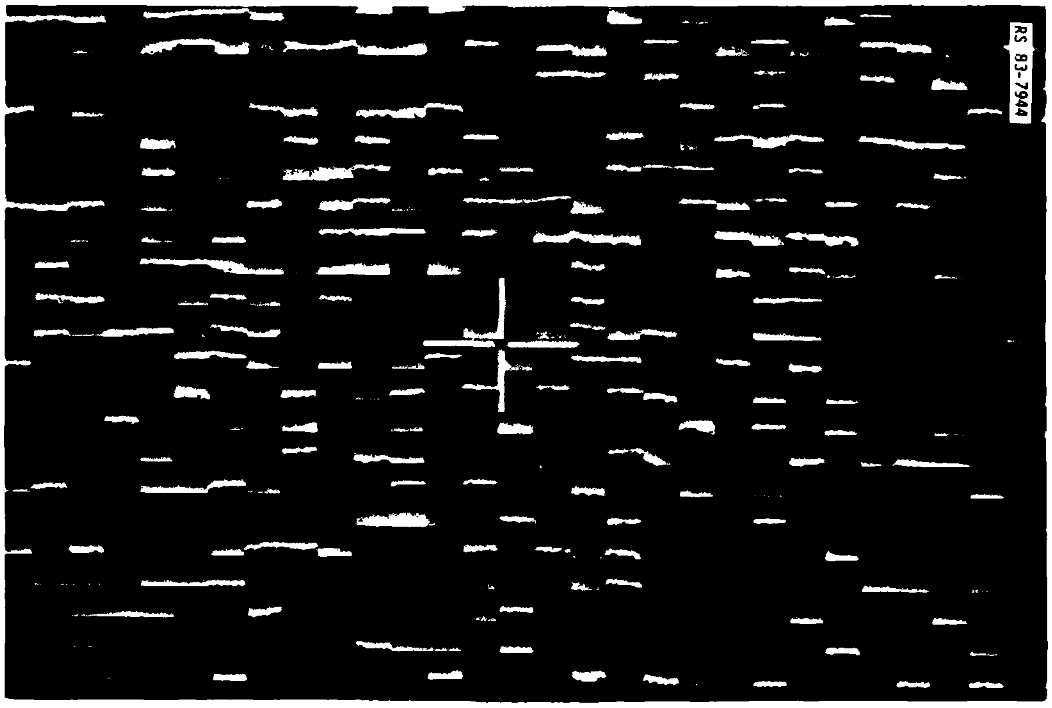


Figure 21. Tank company crossing river.

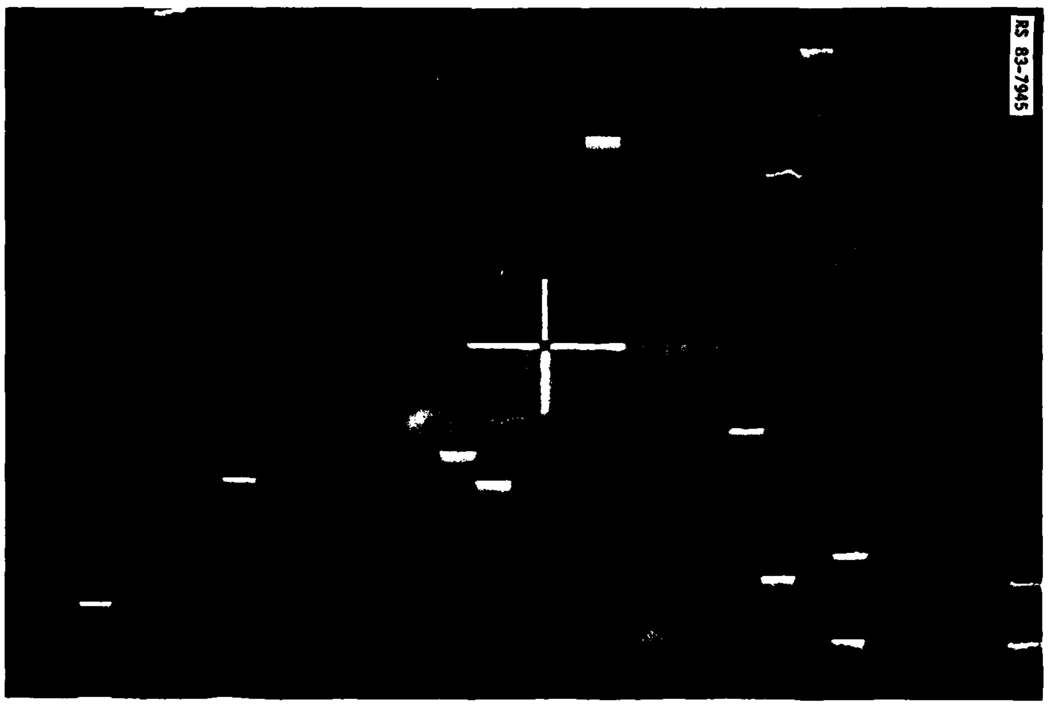
level was a baseline condition and permitted an examination of performance at the maximum 4.6 Mbits per second data rate, while the use of level 3 jamming required the operator to function with the highest selection of antijam and, consequently, the lowest available data rate, 0.072 Mbits per second.

Jamming appeared as "blotches" on the MPO's display. The blotches varied in size and number, depending on the jamming level and the selected antijam level. The size and number of blotches for each jamming level at each of the antijam levels were based on data provided by the Harris Corporation, Melborne, Florida. Harris Corporation is the prime contractor for the RPV MICNS. The blotch size ranged from 16 horizontal pixels by 5 vertical pixels to 64 horisontal pixels by 20 vertical pixels. The size change was directly proportional to the amount of resolution reduction, video truncation, and display zoom. The number of blotches ranged from zero to a quantity that caused video freeze. Video freeze corresponds to loss of RPV video syncronization. The size and number of blotches were faithfully represented in each video frame for all jamming level/antijam levels throughout the simulation. Figure 22 illustrates two of the jamming level/antijam levels used in the simulation.

Each target type was presented at each jamming level. The jam levels were assigned to four sets of the eight target types and four MPOs using a Latin square, and then these target/jamming stimulus pairs were sequenced for presentation to each MPO using a table of random numbers. Table 3 shows the Latin square arrangement to balance jamming levels and targets across MPOs. This design resulted in a set of 32 test stimuli for each MPO (four target types X two missions X four jam levels). A separate set of eight training trials was created for each MPO using a procedure similar to that for building the test trials.



a. JAMMING LEVEL 2, ANTIJAM LEVEL NONE



b. JAMMING LEVEL 2, ANTIJAM LEVEL 3

Figure 22. Two examples of jamming level/antijam levels.

TABLE 3. LATIN SQUARE ARRANGEMENT

TARGET SETS	MPOs			
	1	2	3	4
A	3	2	1	None
B	1	None	3	2
C	2	1	None	3
D	None	3	2	1

NOTE: Table entries are jamming levels.

Procedures -- Operator Preparation

Each operator was given an orientation booklet to read prior to the study. This booklet contained familiarization materials regarding RPV missions (i.e., artillery and Copperhead), target configuration and recognition features, MPO console controls and functions, mission tasks, and RPV study procedures.

In addition to the printed materials distributed to the MPOs, each participant was given a standardized briefing and training session prior to beginning the study. This briefing covered all of the topics included in the booklet, and added a review of target configurations using small models of the major weapons and vehicles found in each target type. The MPO was then quizzed and given feedback, as necessary, until the relevant recognition cues for each target type and the ordnance required for each, reached a criterion of 100 percent correct.

The operator was then seated in front of the MPO console and static examples of each target type were shown on the monitor, using images that would not be included in the actual test sessions. This was followed by an explanation of MPO console nomenclature, where the location and function of each control was pointed out. Another quiz was given at this point, and additional training was provided, until the MPO reached a criterion of 100 percent correct identification of each console control. A demonstration of a typical artillery mission and a typical Copperhead mission were then provided to the MPO, to show the dynamic operation of all controls. These demonstrations could be frozen as necessary to allow the operator to ask questions.

When the MPO indicated that he understood the operation of the console, the series of eight training trials was begun. Details of the trial procedures are discussed below. The test conductor provided advice and feedback during the first four trials, but did not freeze or interrupt the missions in any way. The last four mission trials were conducted without feedback of any kind, but, if performance was judged inadequate after these four trials, additional practice was provided. The criterion for proceeding with the test session was correct performance on four consecutive trials. Correct performance was defined as the ability to find a valid target, determine the appropriate ordnance and establish a target track sufficient to bring artillery to bear or to lase at least two Copperhead targets.

Procedures -- Test Trials

Each trial was configured separately, using an interactive computer program which permitted the specification of the target image and jam level. The mission began with approximately 10 seconds of cruise flight in the target area. If jamming was to be a part of the trial, it was introduced at the beginning; thus, the MPO used these first few seconds to adjust brightness and contrast, and to select the desired antijam setting. The jamming level remained constant throughout the mission.

The RPV was automatically placed in an orbit approximately 10 seconds into the mission. This was indicated to the operator by the lateral motion of the monitor image, when the RPV flew over the terrain in a simulated racetrack pattern. At this point, the MPO began to search for the target. When the MPO believed that a target had been found, it was called out to the test conductor; the MPO then determined what type of ordnance was appropriate. The test conductor examined the area of interest at this time, and recorded whether: 1) the target was, indeed, valid and 2) whether the ordnance selection was correct.

Regardless of whether either or both of these MPO actions were correct, the mission was continued, and the test conductor called out the ordnance that was to be used; this was determined by the target type. The MPO was permitted to establish autotrack on the target prior to ordnance launch. This required the MPO to establish autotracking (Scene or Feature track) and to call out the coordinates of the target centroid for conventional artillery, or entering a Feature Track condition over a tank for Copperhead. Ordnance bursts were called up on the monitor at the appropriate times, using statistical models of firing accuracy.

If the MPO designated the positions of artillery bursts correctly, subsequent bursts landed progressively closer to the target; this accurately simulated the improved firing accuracy which would be expected of artillery crews when a spotter is available to provide feedback about accuracy. If the operator failed to designate a burst, bursts continued to detonate at random positions around the target. The Copperhead firing model was implemented differently, to account for the unique features of this ordnance. Copperhead guidance required the MPO to designate (lase) a tank target during the last 13 seconds of projectile flight. Furthermore, Copperhead projectiles were fired in sets of four, each launched 30 seconds apart. The Copperhead burst always went off at the point lased, if lasing occurred within 13 seconds of projected impact. If this condition was not met, the burst went off at the previous spot lased. Copperhead bursts appeared at the fixed interval of firing, regardless of where the operator was in his designation task. The test conductor, acting as the RPV mission commander, provided warnings of impending detonation, and commands to lase for the MPO.

The artillery firing model usually resulted in a direct hit on the target after three shells. When the test conductor observed such a hit, or when he observed the fourth Copperhead detonation, the MPO was told to stop. At this command, the MPO pushed the Enter button on the console to terminate the trial. When all 32 trials had been completed, the MPO was given a questionnaire to fill out regarding the console and the study. Each operator required approximately eight hours to complete this study, including two hours for training and six to seven hours for the test trials.

MPO performance was measured for the following events during the simulated mission:

- Target detection time
- Correct or incorrect target designation
- Target acquisition time
- Ordnance call-in time
- Correct or incorrect ordnance call-in
- Frequency of Joystick use
- Joystick active time
- Frequency of Field of View use
- Frequency of Zoom use
- Frequency of Polarity use
- Frequency of Antijam use

Frequency of Search mode use

Frequency of Scene Track use

Frequency of Feature Track use

Frequency of Offset Track use

Frequency of Autoreturn use

Frequency of Light Pen use

Number of artillery firings

Number of Copperhead firings on Target.

Running timelines of all the above measures were also recorded to the nearest 0.5 second during the simulated missions for later construction of conventional artillery and Copperhead missions. The discrete event measures were analyzed for statistical reliability of jamming levels, missions, and the interaction between jamming and missions, using analysis of variance procedures. Duncan's multiple range test was used to test for reliability between means when appropriate.

RESULTS AND DISCUSSION

The overall characteristics of MPO performance and observations regarding potential improvements to MPO console design are presented and discussed. In general, the operators were able to perform both missions under even the most severe jamming conditions. Furthermore, each operator offered specific comments regarding system improvement, which were very consistent among the participants.

The results are presented in terms of the four jamming levels for each of the two missions and are organized into four major categories: 1) mission time and success, 2) sensor slewing operations, 3) system modes, and 4) MPO comments and critiques.

Jamming level, the main variable of interest, determined the antijam level selected and thereby determined the frame rate, resolution and truncation conditions during a simulated mission. Once an antijam level was selected, the MPOs rarely changed it. The average value of antijam level selected by the MPOs at the four jamming levels for the two missions is shown in Figure 23. The selected antijam levels were nearly identical for the two missions, and the settings resulted in an essentially blotch-free display for the jamming levels -- 0.03 blotches per video frame for the level 1 jamming condition (three blotches for every 100 video frames) and 27 blotches per frame for the level 2 and 3 jamming conditions in the Search mode. The

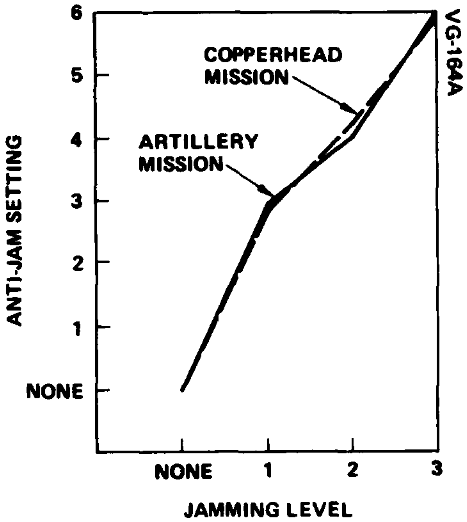


Figure 23. Average antijam level selected.

number of blotches were reduced proportionately with resolution reduction and truncation in the Target and Burst modes.

Mission Time and Success

Target Detection

The time from mission initiation until the MPOs detected the targets in orbit flight is shown in Figure 24. There was a major difference ($p<0.0001$) in target detection time between the conventional artillery and Copperhead missions. Averaged across the four jamming conditions, it took the MPOs 151.2 and 77.8 seconds to detect targets for the artillery and Copperhead missions, respectively. This large difference is hypothesized to be caused by the different target types used in the two missions. The motorized rifle and tank company targets used in the Copperhead missions were easier to detect than the SA-6, supply vehicle, and ZSU-23/4 targets used in the artillery missions. The Copperhead mission targets provided patterns that were more conspicuous, more in open areas, and on average contained a greater number of objects.

Jamming level affected MPO target detection time ($p=0.06$) most notably at the level 3 jamming condition, as shown in Figure 24. This is most likely due to the very slow update rate (0.12 frame per second or 1 frame every 8.5 seconds) when in the search mode and at antijam level 6.

The Copperhead mission also resulted in a higher probability of correct target detection than did the artillery mission ($p<0.05$), as shown in Figure 25. The overall probabilities for the two missions were 0.85 and 0.71.

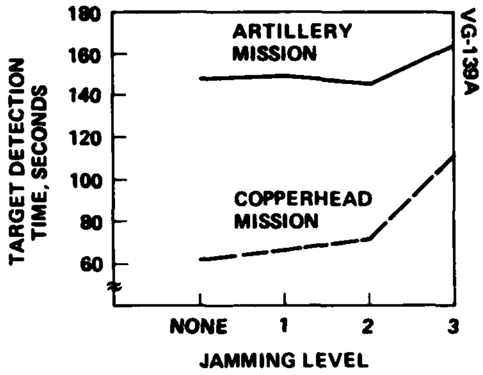


Figure 24. Jamming level effects on target detection time.

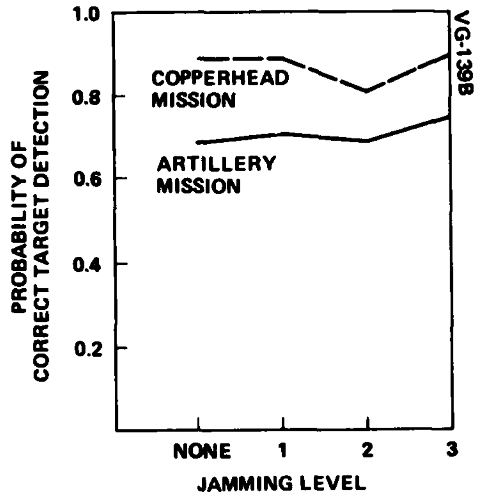


Figure 25. Jamming level effects on probability of target detection.

Jamming level did not affect the probability of target detection. This is as expected, because in the search mode, image resolution remains constant at all antijam levels.

Target Acquisition

Target acquisition is defined as the point at which the MPOs had slewed the target to the laser aimpoint reticle, and had established autotracking. Target acquisition time, which is the time from mission initiation until autotracking was established, is shown in Figure 26. The results are essentially the same as the target detection time results. There were large differences between the two missions ($p<0.0001$). The overall mean target acquisition times for the artillery and Copperhead missions were 188 seconds and 107 seconds, respectively. The effect of jamming level was also statistically reliable ($p<0.0002$), again, with the largest affect at the level 3 jamming condition for the Copperhead mission. This large increase in time at level 3

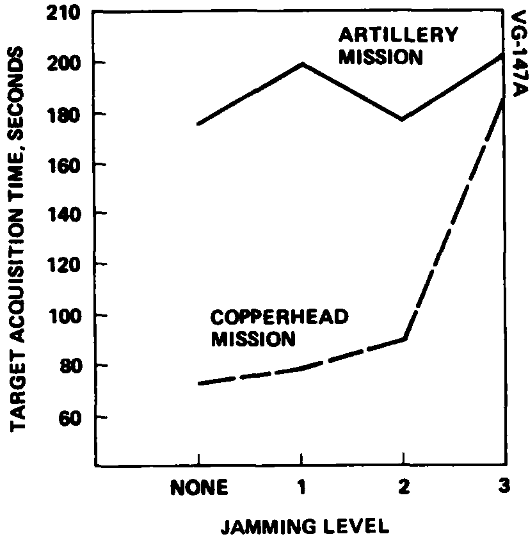


Figure 26. Jamming level effects on target acquisition time.

jamming for the Copperhead mission was responsible for a statistically reliable interaction effect (p=0.05) between missions and jamming levels. Apparently, the low frame rate at level 3 jamming caused the large increase in time for the Copperhead mission with the targets that were relatively easy to detect, while for the artillery missions the driving factor was the difficulty of the targets.

<u>Ordnance Call-in</u>

When the MPOs had slewed the target under the laser aimpoint reticle, established track and recognized the type of target, they were ready to call-in ordnance. Figure 27 shows this time measure for the four jamming levels at the two missions. For the artillery mission, the time ranged from 191 seconds at no jamming to 240 seconds at level 3 jamming; for the Copperhead missions the times ranged from 149 seconds to 265 seconds. The effects due to jamming level and missions on ordnance call-in time largely parallel the target designation time results, except that the degradation at level 3 jamming with the Copperhead mission was more pronounced.

The probability of correct ordnance call-in, namely Copperhead for motorized rifle and tank company targets and conventional artillery for SA-6, supply vehicle, and ZSU-23/4 targets, is shown in Figure 28. The probability of correct ordnance call-in is equivalent to the probability of correct target configuration recognition. Neither jamming level or mission type had an appreciable affect on the probability of correct ordnance call-in. The overall success rate was 0.77.

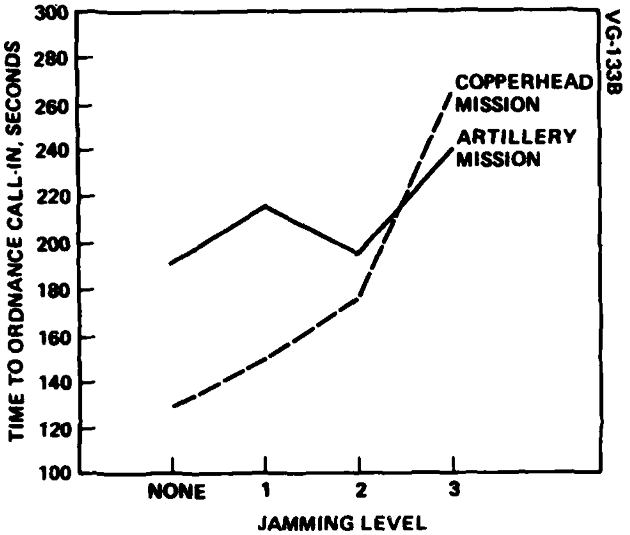


Figure 27. Jamming level effects on time to ordnance call-in.

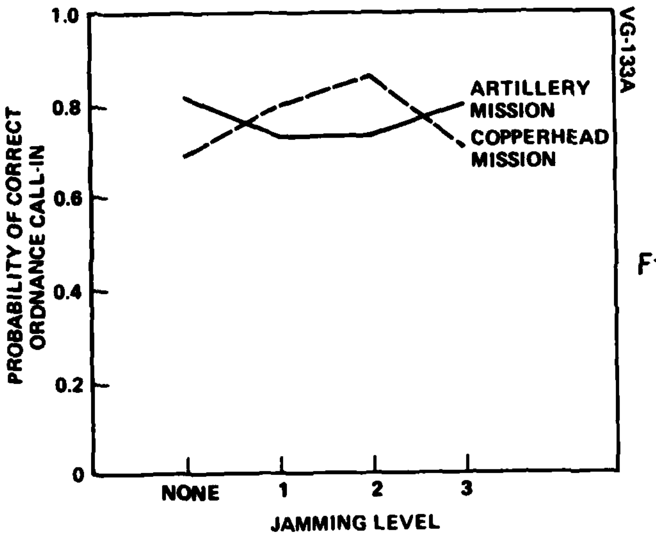


Figure 28. Jamming level effects on correct ordnance call-in.

Total Mission Time

Artillery missions terminated when artillery was delivered on or near (±50 meters) of the target aimpoint; Copperhead missions terminated when the fourth Copperhead round was delivered. The total mission time for the two missions at the four jamming levels is shown in Figure 29. Total mission time for the artillery mission ranged from 348 seconds to 400 seconds. There was little time difference among the no jamming, level 1, and level 2 jamming conditions for the artillery mission, but at level 3 jamming time increased by 40 to 50 seconds. In the Copperhead mission, total mission time increased in a logarithmic fashion from 244 seconds to 377 seconds as jamming level increased. These differences due to missions and jamming levels were highly

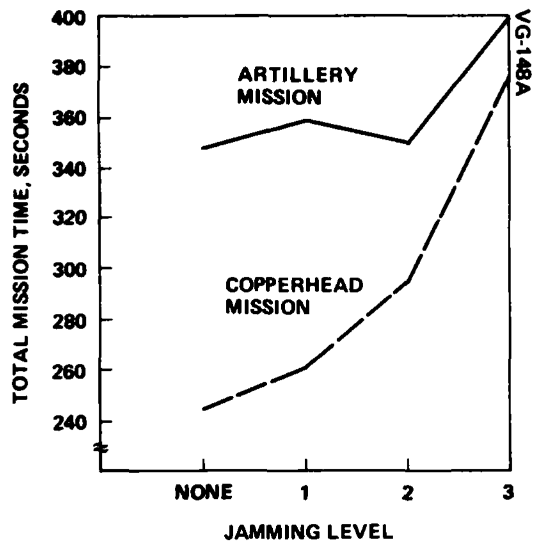


Figure 29. Jamming level effects on mission time.

statistically reliable ($p<0.0001$). The larger times in the artillery mission, compared to the Copperhead mission, are probably caused by the differences in targets; the artillery targets were much more difficult to detect. Conventional artillery delivery time is also inherently larger than Copperhead delivery time, because each artillery round requires a call for fire, computation of firing data, cutting the charge, and artillery flight time. Whereas the second, third, and fourth Copperhead rounds are delivered at fixed 30-second intervals for a 12 km range. The large increase in time for both missions at level 3 jamming is probably caused by the low frame rate when in the search mode. Clearly, if total mission time is important to RPV mission success, the MPOs should avoid operating at antijam level 6.

Representative timelines for the artillery and Copperhead missions are depicted in Figures 30 and 31. Both timelines are for the same MPO at the level 2 jamming condition. A summary of the four mission performance times (target detection, target acquisition, ordnance call-in, and total mission) and the delta times between each of the four successive mission times for the two missions at the four jamming levels is provided in Tables 4 and 5. For both missions, the largest time increments were between mission initiation and target detection and between ordnance call-in and mission completion. It is apparent that the time between target acquisition and ordnance call-in was considerably longer for the Copperhead mission (73 seconds) than for the artillery mission (22 seconds). It is also clear that large relative time increments occurred as jamming increased from level 2 to level 3 between mission initiation and target detection and between target detection and target acquisition for both missions.

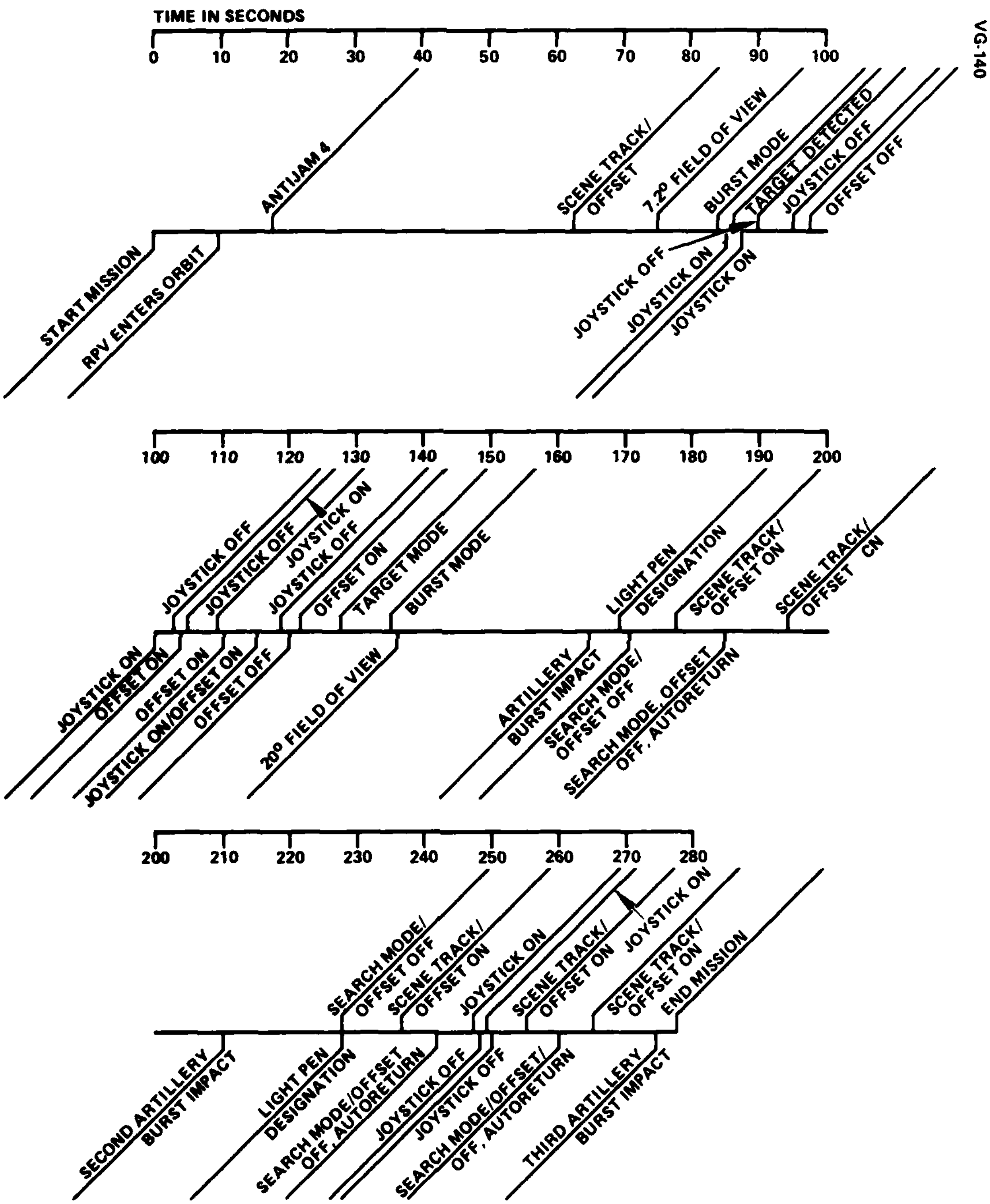


Figure 30. Example of conventional artillery mission timeline.

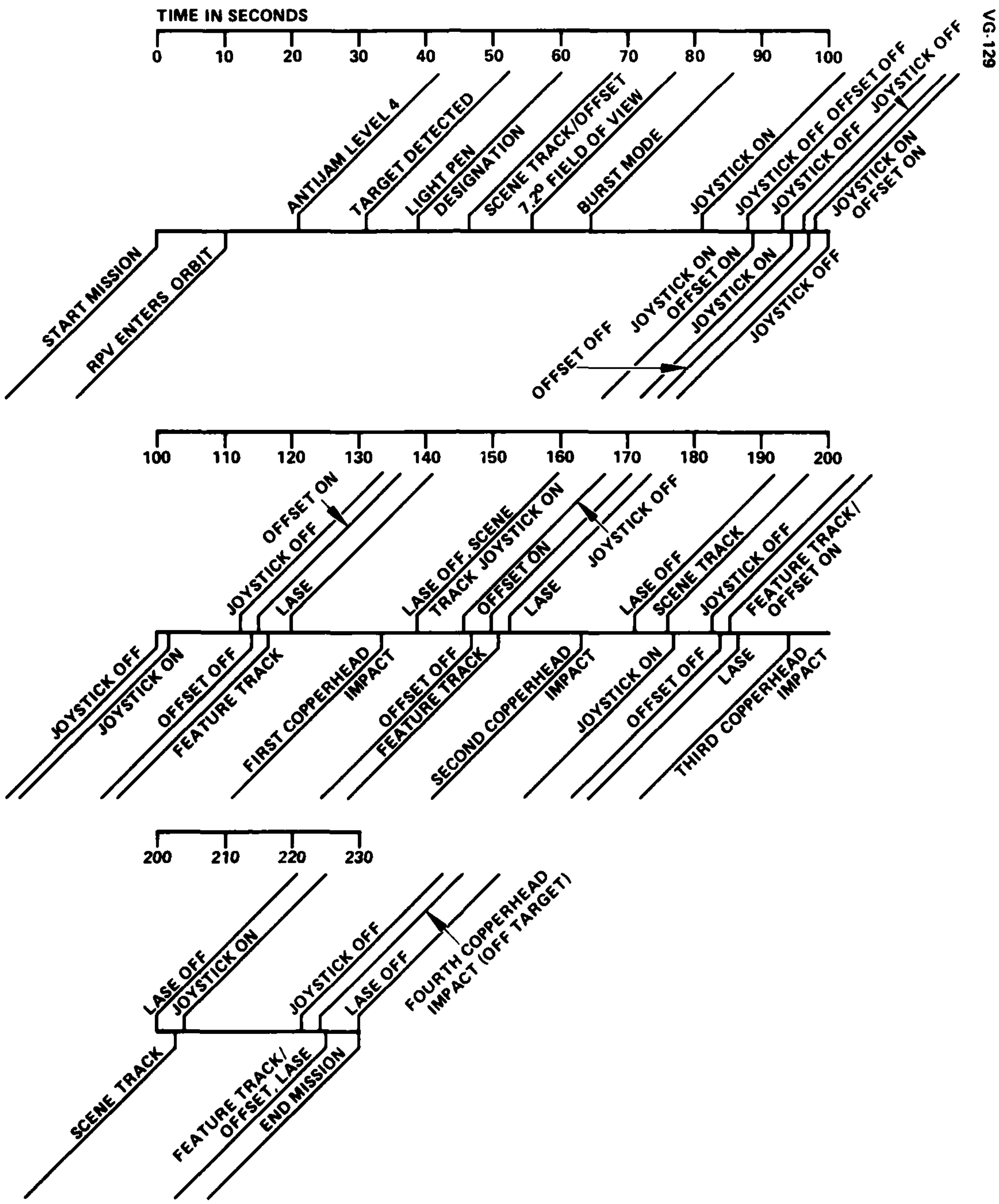


Figure 31. Example of Copperhead mission timeline.

TABLE 4. MISSION PERFORMANCE TIMES AND DELTA TIMES FOR THE ARTILLERY MISSION

JAMMING LEVEL	MISSION PERFORMANCE TIME, SECONDS						
	TARGET DETECTION (T1)	TARGET ACQUISITION (T2)	T2-T1	ORDNANCE CALL-IN (T3)	T3-T2	TOTAL MISSION (T4)	T4-T3
NONE	148	176	28	191	15	348	157
1	148	199	51	215	16	359	144
2	143	178	35	195	17	345	150
3	166	202	36	240	38	400	160
AVERAGE	151	189	38	210	22	363	153

TABLE 5. MISSION PERFORMANCE TIMES AND DELTA TIMES FOR THE COPPERHEAD MISSION

JAMMING LEVEL	MISSION PERFORMANCE TIME, SECONDS						
	TARGET DETECTION (T1)	TARGET ACQUISITION (T2)	T1-T2	ORDNANCE CALL-IN (T3)	T3-T2	TOTAL MISSION (T4)	T4-T3
NONE	62	73	11	130	57	244	114
1	67	79	12	149	70	261	112
2	71	90	19	176	86	294	118
3	112	186	74	265	79	377	112
AVERAGE	78	107	29	180	73	294	114

Sensor Slewing Operation

The MPOs could use either the light pen or the joystick to accomplish sensor slewing. However, the light pen could only be used when the system was in the search mode. The joystick could be used in either the search mode or the feature or scene track modes, and when in the track modes, offset track had to be enabled to effect sensor slewing.

Light Pen Use

As shown in Figure 32, there was greater use of the light pen in the artillery mission ($p<0.001$). The mean number of light pen designations for the "Point" function (sensor slewing) was 5.7, while for the Copperhead mission, the mean was 3.8. Although there were differences across the four jamming levels, they were not statistically reliable ($p>0.20$), and there were no trends.

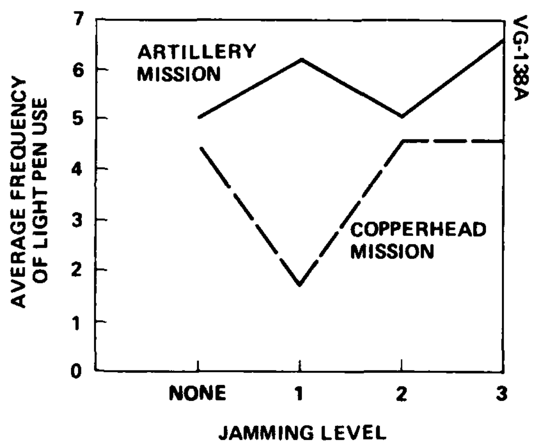


Figure 32. Jamming level effects on frequency of light pen use.

The smaller use of the light pen in the Copperhead mission is understandable in view of the reduced accuracy (it takes two to three light pen designations to achieve a 50-meter pointing accuracy). Hence, precision laser designation for Copperhead delivery is not practical using the light pen, but it is acceptable for conventional artillery.

Joystick Use

The number of times the joystick came out of the deadband is shown in Figure 33. The joystick was more frequently used in the Copperhead mission, an average of 12 times, compared to the artillery mission, 5.5 times. This difference, which was statistically reliable ($p<0.0001$), is a result of

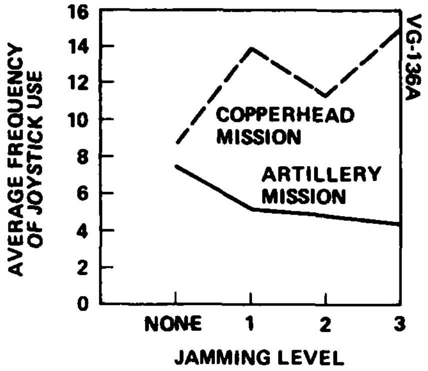


Figure 33. Jamming level effects on frequency of joystick use.

predominately joystick use for Copperhead laser designation and heavy light pen use in the artillery mission.

The trend for increased joystick use with increased jamming in the Copperhead mission and the reverse for the artillery mission is probably due to the fact that in the Copperhead mission the joystick must be used to achieve accurate laser target designation, and at higher jamming levels and consequent higher antijam levels, the joystick is more difficult to use because of the attendent lower frame rates. Hence frequency of joystick use was greater at higher jamming levels in the Copperhead mission. Whereas in the conventional artillery mission, the light pen provides sufficient burst designation accuracy, and the MPOs relied more on the light pen at higher jamming levels rather than use the joystick. The interaction between missions and jamming levels for frequency of joystick use was statistically reliable ($p<0.008$).

Figure 34 shows the average amount of time the joystick was used in a mission. The results directly parallel the frequency of joystick use. The effect of mission type and the interaction between mission type and jamming level were statistically reliable ($p<0.0001$ and <0.002, respectively). The average time out of deadband was 15.5 seconds for the artillery mission and 45.6 seconds for the Copperhead mission.

Offset Tracking

The frequency of offset tracking use was slightly greater for the Copperhead mission than the artillery mission ($p<0.07$). For the Copperhead mission, offset tracking was used an average of 5.9 times, and for the artillery mission, it was used an average of 5.3 times. Jamming level also had a negligible affect on frequency of offset tracking use ($p>0.9$). These results are shown in Figure 35. Greater use of offset tracking in the Copperhead

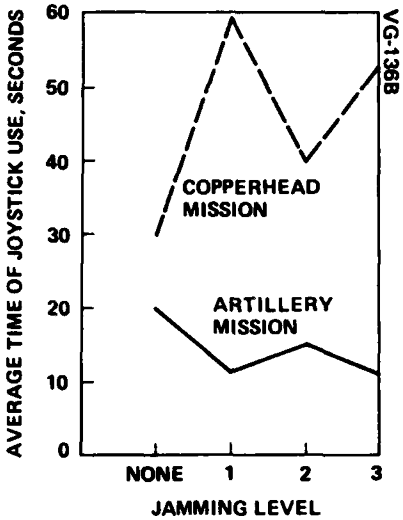


Figure 34. Jamming level effects on average joystick use time.

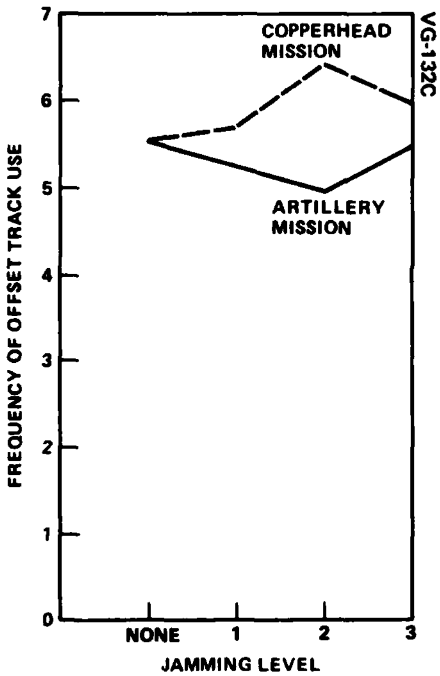


Figure 35. Jamming level effects on offset track use.

mission, because of greater joystick use for precision laser designation, was an expected result.

Control Console Operations

In addition to antijam level selection and sensor slewing control, the MPO has a number of control functions he must or can use during mission payload operations. The frequency of using such controls for the artillery and Copperhead missions is discussed here.

Sensor Field of View

Figure 36 shows the frequency of changing field of view (FOV) for the two missions at the four jamming levels. The overall greater number of FOV changes with the artillery mission, an average of 5.2 changes in a mission, compared to the Copperhead mission, an average of 3.1 changes, is probably due to switching back to a 20-degree FOV for artillery burst detection and then to a smaller FOV to designate the artillery burst. In the Copperhead mission, there is no need to switch back to a large FOV during ordnance delivery, if all four targets are within the sensor field of view. The difference between missions was statistically reliable ($p<0.0001$). The frequency of changing FOV decreased with increasing jamming levels for the artillery mission, and the reverse occurred for the Copperhead mission. The cause of this reliable interaction effect ($p<0.003$) is unknown.

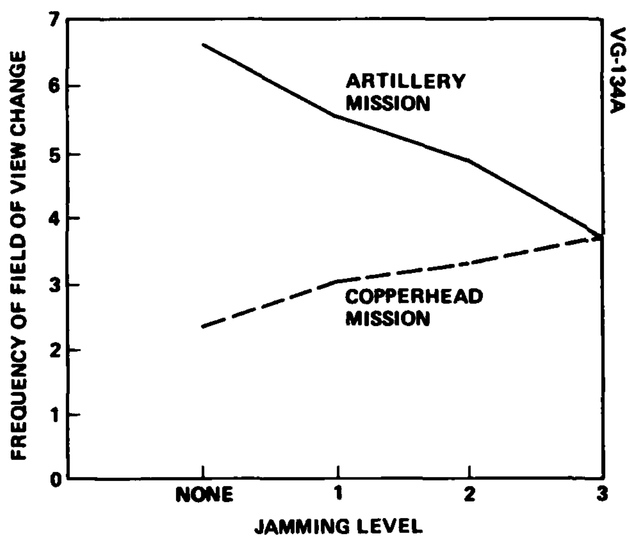


Figure 36. Jamming effects on field of view change.

Search Mode

The number of times the MPOs selected the search mode is shown in Figure 37. In the artillery mission, the search mode was selected an average of 4.8 times, and in the Copperhead mission, the search mode was selected an average of 2.4 times ($p<0.0001$). Jamming level did not reliably affect search mode use ($p=0.09$). The greater use of the search mode in the artillery mission is probably due to artillery burst operations, where the MPO needs to be able to slew across a fairly large angle, using either the joystick or the light pen. If the light pen could be used in any mode, the greater need to use the search mode in the artillery mission may not be necessary.

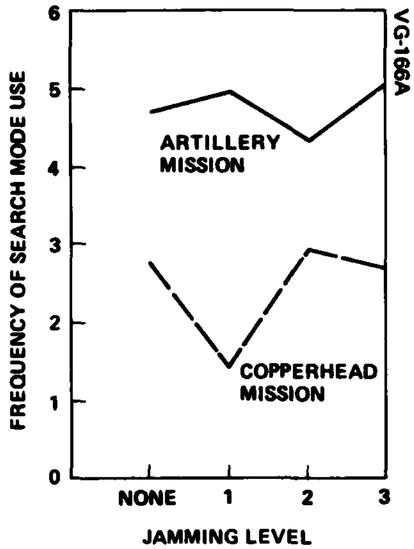


Figure 37. Jamming effects on search mode use.

Feature Track

The MPOs were instructed to use the feature track mode for Copperhead laser target designation because of the greater autotracking accuracy compared to the scene track mode. Figure 38 reflects these instructions. Feature track was used an average of 3.6 times in the Copperhead missions and an average of 0.094 times in the artillery missions ($p<0.0001$). There was also a trend for the frequency of feature track use to increase with increased jamming level ($p=0.05$). The nearly total lack of use of feature track in the artillery mission is probably a reflection of the limited offset tracking capability with the small tracking window during precision feature autotracking. The scene track mode with its larger tracking window would be a better choice for offset tracking operation as long as high precision is not required.

Scene Track

Scene track was used with slightly greater frequency in the artillery mission than in the Copperhead mission -- 4.8 times compared to 4.0 times. This slight difference was statistically reliable ($p<0.0004$). Differences in scene track use caused by the jamming levels were not statistically reliable ($p=0.3$). However, in some cases, as shown in Figure 39, the differences for the Copperhead mission were as large as the differences between the two missions. Operationally, the effects of jamming levels and missions on scene track use are of minor consequence.

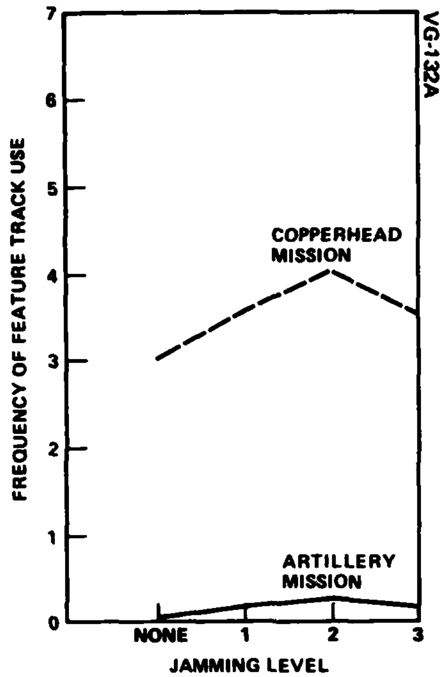


Figure 38. Jamming level effects on feature track use.

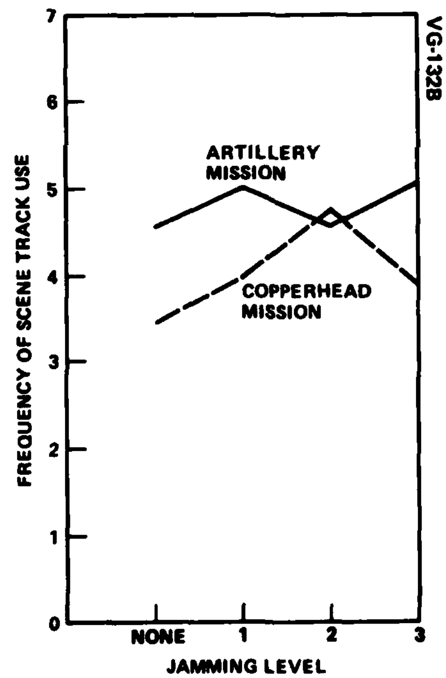


Figure 39. Jamming level effects on scene track use.

Autoreturn

The principal use of the autoreturn function is in the artillery mission to rapidly achieve sensor pointing to the target after an artillery burst has been designated. This use is clearly depicted in Figure 40. Autoreturn was used on average of 2.0 times in the artillery mission; in the Copperhead

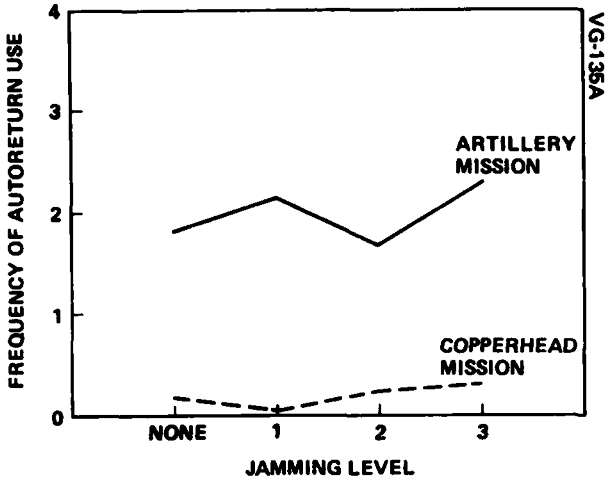


Figure 40. Jamming level effects on autoreturn use.

mission, autoreturn was rarely used -- an average of 0.16 times. Jamming level did not affect autoreturn use ($p=0.12$). The effect of missions on autoreturn use was statistically reliable ($p<0.0001$).

Zoom

Electronic zoom was never used by the MPOs. During training, the MPOs discovered that zoom, which is a MPO selectable option when video truncation occurs, increased the scale factor and degraded the image quality (the image looked blocky and edge sharpness was reduced). In effect, the viewer wants to move back from the display. Since the larger scale factor with increased target size offered no apparent benefit and the image looked worse, the MPOs declined to use zoom.

Polarity

At mission initiation, the display symbology was white. In the vast majority of cases, white symbology was preferred. Hence, the MPOs never bothered to switch to black symbology. For RPV systems with television sensors, the targets are usually dark, and white symbology would be preferred. Future RPV systems with FLIR sensors will result in both light and dark target images. Therefore, a white/black symbology polarity capability should be useful for RPVs with FLIR sensors.

MPO Comments and Critique

Responses to questionnaire items were surprisingly consistent and supported the performance data. In many cases, MPO comments significantly expanded the performance data. The questionnaire form is provided in the Appendix.

The first questionnaire item asked about the difficulty in using the console. Most respondents felt that the joystick was difficult to use, with a strong tendency to overshoot the intended target. This is, most probably, a combined effect of the joystick shaping function and the slow frame rates, which tend to decouple the operator from the effects of control inputs.

The MPOs were also asked about what was most confusing about the MPO console. The implementations of Offset Track, depending on whether Scene or Feature track was selected, generated the most negative response. Currently, the Scene/Offset Track combination results in the image and track box over a new position on the video image when Offset is disabled, while the Feature/Offset combination will return the image and track box to the position originally tracked before Offset was used. The MPOs wanted consistency in these functions. One respondent stated that he kept forgetting to select Search when using the light pen, and that he found himself repeatedly trying to use the Point function from a track condition, which is not an operable mode. Related to this error was dissatisfaction with the console information, regarding which controls were active at any particular time. Another MPO asked that the range of image travel for Offset Track be expanded for future implementations; frequently, MPOs had to disable and re-enable Offset Track to "walk" an image across a large portion of the display, taking up considerable time in the process.

Most MPOs felt that the light pen, together with the Point function, was the most effective way of achieving a stabilized target image, these controls established a stable image for target inspection which would be slewed easily or turned into a video track. This method of moving around an image was popular for artillery burst designation, even when a track condition had to be exited and re-entered to gain new coordinates. Only the Copperhead lasing task resulted in a preference for Offset Track.

The items which the MPOs would most like to change on the MPO console are essentially the same as the problem areas pointed out above, and include consistency in Offset Track for Scene and Feature track modes, and expanded range of image movement in Offset Track. Other suggestions included lower actuation forces for pushbuttons, improved shaping function for the joystick, and extended kick space beneath the console.

Other suggestions were made for additions to the MPO console, and extend the ideas given above. One MPO stated that a time display be included, to indicate lasing time. Another suggested voice control capability to surmount the "one-armed paperhanger" feeling under high task loading. A third idea concerned effective use of otherwise dead time in the designation task through use of two reticles. In this scheme, one reticle would indicate the current designation point and a second would show the next intended point; the operator could control this second reticle while he was designating an artillery target or burst, or lasing a tank for Copperhead. This approach to target inputs would make profitable use of time that the MPO is currently not employing, limited as he is to hold the target on the laser aimpoint reticle until the task at hand is complete and then making a rapid transition to some new point. Most of the MPOs specified the Zoom control, when asked what items they would remove from the console. The MPOs also emphasized the importance of training.

SECTION 4
CONCLUSIONS AND RECOMMENDATIONS

The results showed that jamming can increase the time required to detect and acquire targets and to complete missions, but it was also shown that MPOs with relatively little training are capable of performing both artillery and Copperhead missions with reasonable success, even under severe jamming. The bit error rate jamming levels simulated, effectively led to an evaluation of antijam levels None (no data rate reduction), 3, 4, and 6. The results indicated that antijam level 6 would produce a major increase in the time to accomplish both conventional artillery and Copperhead missions. MPOs should therefore avoid the use of this worst case operating condition. While it was recognized in the design of the simulation study that level 3 jamming will rarely be encountered in actual operations, it was included as a worst case condition. Therefore, operation at the level 6 antijam level should not be a problem, because of the low probability that level 3 jamming will be encountered.

The artillery mission required significantly greater time to complete than the Copperhead mission, primarily because of the greater difficulty the MPOs experienced detecting the artillery mission targets. Once the MPOs found the artillery mission targets, they always successfully completed the mission, directing artillery on the targets after two to three rounds had been fired. While the Copperhead missions required less time to complete, the MPOs were generally unable to direct four Copperhead rounds on four targets. An average of 2.4 targets were destroyed in the Copperhead missions. This inability to destroy four targets with four rounds was caused by the restricted sensor slewing capability in the Offset Track mode. Both the range (distance) and the rate of offset sensor slewing are restrictive. Modification of MPO system operation is clearly needed for Offset Track.

Questionnaire responses showed certain trends in control preference and certain ideas for other possible RPV system improvements. Primary among these was a suggestion to implement Offset Track in only one way -- the manner currently used for Scene Track. Other major suggestions were to modify the joystick shaping function, to provide clearer indications of which controls and modes are active at any one time, and to indicate Autoreturn and Cued Target location via display symbology. Enhancements to the MPO console included suggestions for addition of a laser firing timer, a current/future reticle positioning capability, and activation of controls by voice input.

The MPO performance levels obtained in this simulation with the current console design were highly encouraging. As with most new systems, however, the MPO console could benefit from further modification, and the potential improvements in operator performance from such changes could be significant. All of the MPOs' suggestions for console enhancements deserve serious review; in many cases, MPOs could have improved their performance if the console had been implemented differently.

These observations indicated that additional performance studies are desirable for greater payoff from the Aquila RPV system. The issues of highest, or most immediate, interest are grouped here according to operators, console design, and target imagery.

The training sessions for this simulation were sufficient to equip each MPO with a working knowledge of the RPV system and the targets to be found. Additional performance improvement can reasonably be expected if this training is expanded, but the asymptote of such performance is not known. Thus, a parametric examination of operator training issues against resultant performance would be of benefit for further studies and for training on the operational system. A considerable body of human performance literature has also been generated concerning search strategies with different types of sensor imagery. These data should be explored in the practical setting of the RPV missions and studied in conjunction with other RPV variables. Although the current study utilized a limited number of Hughes engineering personnel, with satisfactory results, it is not too early to begin examining operator characteristics, through structured testing, to help establish selection criteria for the mission payload operators. This is a new system with new personnel demands, and its critical missions require that MPOs be carefully screened.

The current MPO console provides a myriad of functions, which increased the MPOs' decision and task load, and led to slower operation and/or increased risk of error. A systematic examination of controls is needed to empirically determine which ones are important and which ones can be eliminated. A more ambitious effort is required, of course, before firm decisions are made. Other console additions also need to be considered for possible performance improvement, such as voice control and double reticles. Observations of the MPOs indicated that automatic antijam might be faster and more appropriate than the strategies seen in this simulation. There is also evidence from this simulation and prior research to suggest that the 21 combinations of frame rate, resolution, and truncation selected are less than optimum.

New approaches to MPO console design, with the potential for substantial improvement in operator performance, should be considered. The ability to go from Feature or Scene Track to Light Pen designation, for example, without transitioning through Search would have been a boon to the MPOs in the simulation. Such ideas deserve study by human engineering personnel before a final console design and operating concept is selected. Screen symbology is also an issue which was identified in this study as an area for potential development; additional symbols may significantly aid the MPO for more rapid and accurate control inputs.

The current RPV system is usable in its existing form, and substantial performance may be expected with this design. Further study will be needed, however, to insure that the console design and operating procedures are not limiting factors of Aquila capability.

APPENDIX
POST-SIMULATION STUDY QUESTIONNAIRE

1. What did you find most difficult to use about the RPV console operation?
2. What did you find the most confusing about the RPV console operation?
3. What controls did you find worked best for you to establish a target track?
4. What thing(s) would you change to the existing RPV console?
5. What thing(s) would you add to the RPV console?
6. What thing(s) would you remove from the console?
7. Any comments on the procedures or objectives of either mission?
8. Any comments on the conduct of the study?
9. Anything to say about anything not covered in this questionnaire?

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